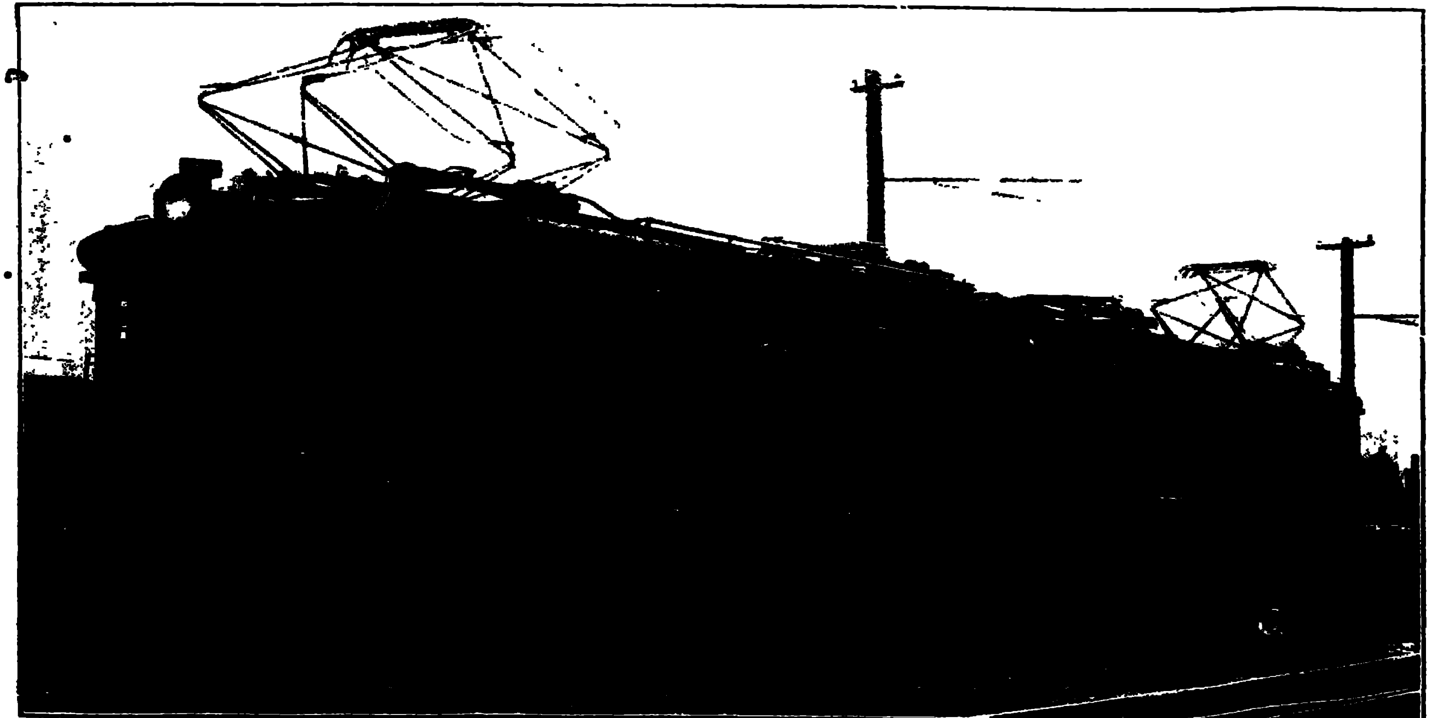
The theoretical man knows *why*. The practical man knows *how*. The man who would lead must know why *and* how.



MOTOR GENERATOR TYPE LOCOMOTIVE FOR FREIGHT AND PASSENGER OPERATION

Courtesy of Westinghouse Electric and Manufacturing Company

Electrical Engineering

A General Reference Work on

Electrical Principles, Direct-Current Dynamos, Direct-Current Motors, Storage Cells, Armature Winding, Design of Small Motors, Transformers, Meter Testing, Magneto Design, Controllers, Signaling, Power Stations, Electric Wiring, Radio, Switchboards, Station Management, Welding

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Grateful acknowledgment is here made also for the valuable cooperation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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140,000-VOLT ALUMINUM LIGHTNING ARRESTER AT ZILWAUKEE, AU SABLE ELECTRIC COMPANY

Courtesy of General Electric Company

Foreword

ELECTRICITY has been compared to the giant slave which did the bidding of Aladdin and his wonderful lamp. Touch a button and the room is flooded with light. A turn of the dial on the radio selects music or other entertainment from numerous sources; brings to us the vivid description of an athletic or public event as it is seen by a spectator; enables a president to talk to his countrymen in a nation-wide hook-up. The sturdy electric motor places strength and power behind the skill of the craftsman and multiplies his production many times. Power, light, heat, sound, and even vision are transmitted long distances over wires. And, yet, the ease with which we may control this powerful giant—Electricity—and make him do our bidding is no more fantastic nor fatiguing than was the rubbing of the mythical magic lamp.

¶ Today Electricity has become such an intimate part of our life that its benefits are taken as a matter of course, even though sometimes its workings are not fully understood by all of those who receive its advantages. The application of electricity, however, follows definite laws. There are strict rules for its control and as long as these are obeyed it is our servant. It is the purpose of these volumes on Electrical Engineering to give a simple explanation of the practical working requirements which are essential for an understanding of the principles and laws governing the generation and application of electrical energy.

¶ These books, which have been revised repeatedly to keep them in line with the rapid advance of the industry, contain a logical discussion on such

subjects as Direct-Current Dynamos, Motors, Storage Batteries, Armature Winding, Design of Small Motors, Transformers, Meter Testing, Magneto Design, Controllers, Power Stations, Welding, and Radios. Special attention is given to the information which the operating man must have; the construction as well as the management of devices, instruments, and machines in practical use, and especially the treatment of operating troubles.

¶ The information is as scientifically correct as any such work could be, and yet the treatment of the various subjects is as free as possible from abstruse mathematics and unnecessary technical phrasing, particular attention being given to the careful explanation of any involved but necessary formulas. Diagrams, curves, and practical examples are given whenever it is felt that they may be helpful in explaining the subject. Numerous illustrations and inserts furnish complete pictorial aid to the texts.

¶ Books on Electrical topics, if all gathered in a common library, would contain so much duplicate material that anyone trying to keep up with electrical progress would lose a great deal of time. To overcome this difficulty, the publishers have gone to original sources and secured as writers on the various subjects, men of wide practical experience and thorough technical training. Each writer is a recognized authority on the subject which he covers. The contributions of these men have been correlated by our Editors into these logical and unified volumes.

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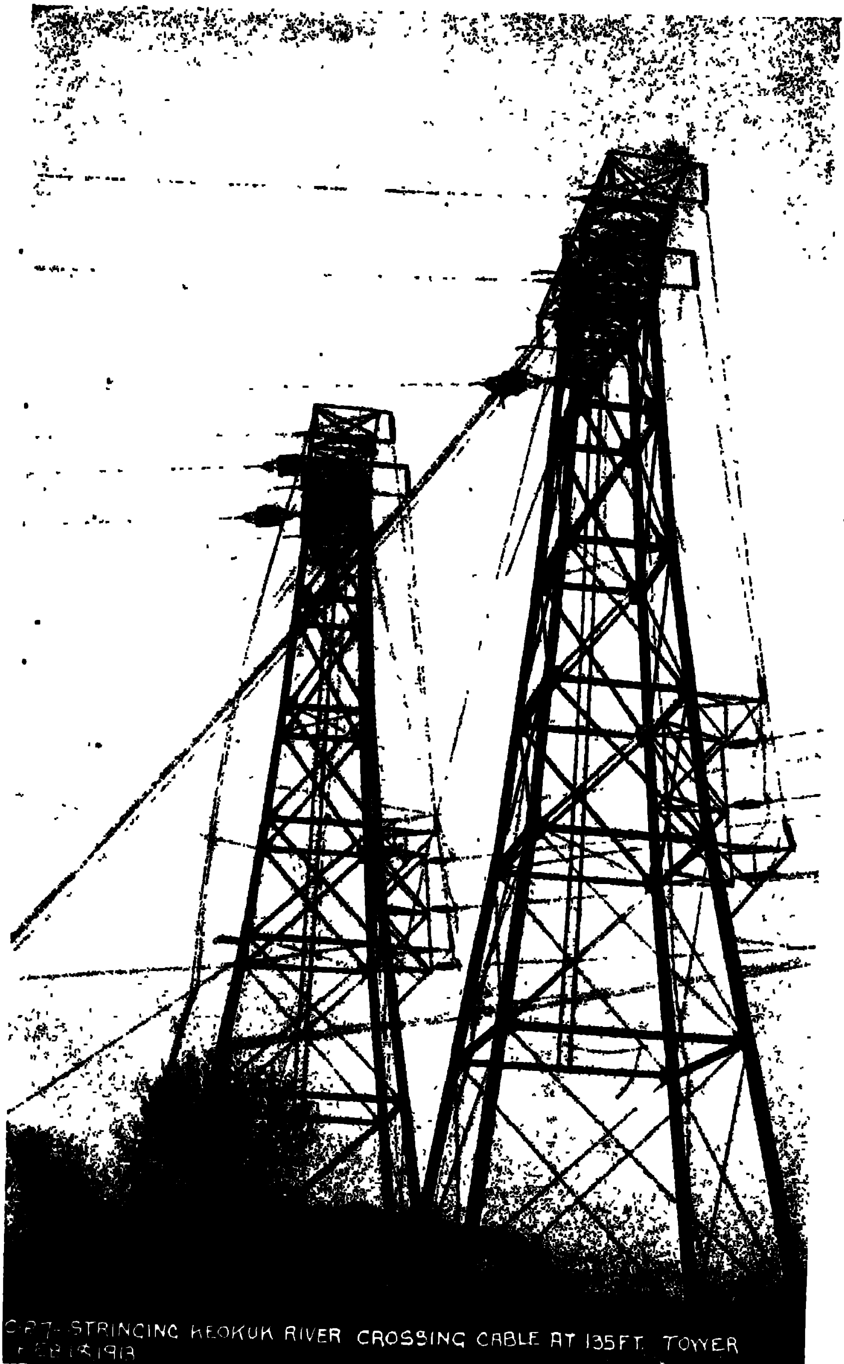
†For professional standing of authors, see list of Authors and Collaborators at front of volume.



SPECIAL 135-FOOT TOWERS USED FOR MISSISSIPPI RIVER CROSSING AT HAMILTON, ILLINOIS, IN CONNECTION WITH THE MISSISSIPPI POWER DAM AT KEOKUK, IOWA

Courtesy of Mississippi River Power Company

ELECTRICAL TRANSMISSION LINES

INTRODUCTION

Basis of Transmission Systems. The existence of extensive transmission systems, covering hundreds of miles and involving great distances, is commercially justified by the fact that transmission lines can be erected at a small part of the cost per kilowatt of generating stations. It is therefore more economical to locate a large generating station at the point where the supply of fuel and water is cheapest or where water power is available, thence transmitting the power to the point of consumption, than it is to build smaller stations at numerous places. There is a further saving in the cost of the generating station because of the lower cost per kilowatt of large units and of the buildings and equipment which accompany them.

The transmission lines act as great arteries carrying the flow of power to centers of distribution, whence it is delivered to the consuming devices, thus supplying the basis of strength to the industrial world.

Line Capacity. The transmission line is fortunately capable of great elasticity as regards its capacity to carry power. With alternating current the transformer makes available any voltage which is desired up to 150,000 volts or more, and the same wires which are capable of carrying 1000 kilowatts at 6600 volts with a loss of 10 per cent will carry 10,000 kilowatts at 66,000 volts ten times as far with the same percentage of loss.

With copper as a conductor and with the three-phase system it should be remembered that when a conductor is loaded to a current density of 1 ampere per 1000 circular mils there will be an energy loss on the line of about 10 per cent when the length of the line is 1 mile per 1000 volts of line pressure. For instance, a line of No. 0 wire operating at 33,000 volts has an energy loss of 10 per cent at a distance of 33 miles when the current is 105

amperes; No. 0 wire has an area of 105,500 circular mils and a resistance of 0.528 ohm per mile. The loss on each wire at 105 amperes is

$$I^2R = 105^2 \times 0.528 = 5820 \text{ watts per mile}$$

or

$$I^2R = \frac{3 \times 33 \times 5820}{1000} = 576 \text{ kw.}$$

for 33 miles. The energy carried by the line at 105 amperes is $\frac{3 \times 105 \times 33000}{1.73 \times 1000}$, or 6000 kilowatts, hence the loss is $\frac{576}{6000}$, or 9.6 per cent.

The preceding calculation assumes the power factor (p.f.) to be 100 per cent. If the power factor were 80 per cent, the energy loss would be the same, 576 kilowatts, but the load on the line would be 0.8×6000, or 4800 kilowatts, and the loss would be $\frac{576}{4800}$, or 12 per cent. Hence the rule is modified by the power factor, and if the loss is to be limited to 10 per cent, the size of copper must be increased or the voltage raised in proportion to the ratio $\frac{100}{p.f.}$.

With aluminum the current density at 10 per cent and 1000 volts per mile is about 0.6 ampere per 1000 circular mils.

Characteristics of Alternating-Current Lines. *Phases.* Transmission lines are quite universally operated three-phase, three-wire (except for small loads), since such lines require but 75 per cent as much conductor metal as do single-phase lines. Single-phase lines are cheaper to construct than three-phase in case the load is so small that the wire chosen to carry the current is of the minimum size required for mechanical strength; under these conditions the cost of one conductor is saved by using a single-phase line. Lines are sometimes built single-phase with space reserved for a third conductor to be installed when the load shall have grown sufficiently to require it. The carrying capacity of the line is doubled by the addition of a third wire.

Frequency. The most common frequency is 60 cycles, but 25 cycles and certain odd frequencies are in use. These do not

affect the transmission line except in the determination of the line drop and the charging current. The frequency is fixed by the conditions under which the power is utilized, 60 cycles being used for general purposes and 25 cycles for railways and d.c. converters. The odd frequencies were established during the early years, when practice had not been standardized and their use will gradually disappear.

Voltages. Certain voltages have been somewhat standardized by American manufacturers for the sake of uniformity. These are taken as multiples of 1100 for the most part, and run 6600, 11,000, 13,200, 22,000, 26,400, 33,000, 44,000, 66,000, 88,000, 110,000, 140,000, etc. The highest voltage employed in any extensive system up to 1919 is 150,000 volts.

In general, the voltage of a line is chosen on the basis of about 1000 volts per mile or higher. If the amount of energy to be distributed is very large or if a 10 per cent loss is likely to be troublesome in maintaining voltage regulation, a higher voltage is often used.

In a system having several generating stations there are often two or more voltages, a higher one such as 66,000 for trunk-line service between stations and main points of use, and a lower one such as 13,200 for use in taking care of service in towns, large industrial establishments, and the like. This use of a lower voltage permits a much less expensive type of substation equipment and line construction, so that the total installation involves a smaller investment than would be required if the entire system were operated at 66,000 volts.

The cost of substation equipment, such as arresters and transformers, increases rapidly as the voltage is increased above 40,000, and if there are a considerable number of receiving stations, the extra cost of the substation equipment may be sufficient to offset the saving in copper made by the use of the higher voltage. Furthermore, there is no saving to be effected by increasing the voltage beyond the point where the size of the conductor cannot be further reduced for mechanical reasons. On the contrary, there may be an increased cost due to the higher cost of the insulators and the wider spacings which would be required because of the higher voltages.

CALCULATION OF LINES

GENERAL FACTORS

Energy Loss. The determination of conductor sizes for a given loss and pressure regulation for lines at voltages below 33,000 involves only the resistance and the inductive reactance of the line. For longer lines and higher voltages the electrostatic capacity of the line is an appreciable factor and must be taken into account. With steel conductors and very small loads the charging current sometimes amounts to an appreciable part of the load current and may cause the overloading of transformers supplying energy to the line.

The energy loss in kilowatts with balanced load on a three-phase line is $\frac{3I^2R}{1000}$, where I is the current in each wire, and R is the resistance of each conductor. If the load is unbalanced, the loss is the sum of the values of $\frac{I^2R}{1000}$ taken for each phase separately. The loss on a 20-mile line carrying 150 amperes per phase and having a resistance of 0.049 ohm per 1000 feet is $\frac{3\times150^2\times20\times5.28\times0.049}{1000}$, or 351 kilowatts. The energy carried by the line at 33,000 volts and 80 per cent power factor is $\frac{3\times150\times33{,}000\times0.8}{1.73\times1000}$, or 6860 kilowatts. Hence the loss is $\frac{351}{6860}$, or 5.1 per cent.

Economic Size of Conductor. In selecting the size of copper for a line it is usual to assume an allowable percentage of loss, such as 10 per cent at the time of full load. This, however, ignores certain elements of cost which require consideration in some cases. The annual cost of operating a line is made up of the following factors: fixed charges on line investment *a;* fixed charges on generating capacity required to supply line losses *b;* and the cost of the energy dissipated by I^2R loss in the lines *c.* Each of these factors may be expressed in terms of R, the resistance per mile of conductor in the line, since they all vary as R is increased or decreased.

It can be shown that the sum of these three elements is a minimum when IR equals $\sqrt{\frac{a}{b+c}}$, in which a, b, and c are constants the value of which may be determined for any given set of conditions, a being proportional to the fixed charges on the conductor, b to the fixed charges on the generating equipment, and c to the cost of energy lost per annum on the line.

For bare copper the weight W multiplied by the resistance R per mile is

$WR = 875.8$ and the weight per conductor mile is

$$W = \frac{875.8}{R}.$$

With copper at 25 cents per pound the cost per conductor mile is

$$0.25\ W = \frac{0.25 \times 875.8}{R} = \frac{\$218.9}{R}.$$

Assuming interest at 6 per cent and insurance and taxes at 2 per cent, the fixed charges on the conductor are

$$\frac{a}{R} = \frac{0.08 \times 218.9}{R} = \frac{17.5}{R} \text{ per mile.}$$

$$a = 17.5$$

The generating station capacity, transformer capacity, etc., required to supply the line loss is $\frac{I^2R \times \text{p.f.}}{1000}$ kilowatts. If the cost per kilowatt of capacity is \$90, and interest, taxes, and depreciation are taken at 12.5 per cent, the fixed charges are

$$bI^2R = \frac{90\ I^2R \times 0.125}{1000} = 0.01125\ I^2R$$

$$b = 0.01125$$

The cost of the energy loss varies both with the load factor of the line and the unit cost of production. If the load factor is 30 to 40 per cent, the annual loss usually amounts to about 25 per cent of the loss at the time of full load, multiplied by 8760 hours. The energy loss is $\frac{0.25 \times 8760\ I^2R}{1000}$ kilowatt hours per annum. Taking the cost of energy at 0.6 cent per kilowatt hour, the cost of the loss is

$$cI^2R=0.006\times0.25\times8.76\ I^2R=0.01314\ I^2R$$

$$c=0.01314$$

For the conditions assumed above

$$IR=\sqrt{\frac{a}{b+c}}=\sqrt{\frac{17.5}{0.01125+0.01314}}=\sqrt{\frac{17.5}{0.02439}}=\sqrt{717}=26.7$$

If the full-load line current I is 100 amperes, the value of the resistance per mile R is $\frac{26.7}{100}$, or 0.267 ohm, which is approximately the resistance of No. 0000 conductor, or 0.258 ohm, Table I.

The fixed charges on the line with No. 0000 are

$$\frac{a}{R}=\frac{17.5}{0.258}=\$67.82 \text{ per mile.}$$

The fixed charges on the generating capacity are

$$bI^2R=0.01125\times100^2\times0.258=\$29.03$$

The cost of the energy loss is

$$cI^2R=0.01314\times100^2\times0.258=\$33.90$$

The total annual cost is 67.82+29.03+33.90, or \$130.75 per mile.

If No. 0 conductors are used for this current, the resistance per mile is 0.5188 ohm and the annual cost for line charges is

$$\frac{a}{R}=\frac{17.5}{0.5188}=\$33.73$$

for station charges

$$bI^2R=0.01125\times100^2\times0.5188=\$58.30$$

for cost of line loss

$$cI^2R=0.01314\times100^2\times0.5188=\$68.17$$

The total annual cost per mile is 33.73+58.30+68.17, or \$160.20, which is about \$30.00 higher than the cost for No. 0000 conductor.

The most economical size of conductor is thus determined by the value of the current at full load I without regard to the length of the line. In the case of lines having less than 5 to 7 per cent loss the saving made in generating capacity cannot always be realized since it is represented by the voltage regulation of the generator rather than by load in the armature. For this reason it is usual in practice to make the size of the line such

that the fixed charges on the conductor approximately equal the cost of the energy loss. This gives a higher current density and reduces the size of the conductor to about 1200 to 1500 circular mils per ampere.

Voltage Regulation. For lines on which the charging current is not an appreciable factor, the line drop is dependent on the resistance and the inductive reactance of the circuit and on the power factor of the load carried by the line.

The resistance and the reactance of the various sizes of conductors at 60 cycles, with the spacings between conductors commonly found in transmission lines, are given in Table I. The values of inductive reactance in Table I are based on the formula

$$X = 5.28 \times 0.377 \ (0.141 \log \frac{D}{d} + 0.0576)$$

in which X is the reactance, D is the distance between centers of conductors, d is the diameter of the conductor in inches, and the logarithm is to the base 10. The values of inductance for the sizes larger than No. 0 are for stranded conductors; these values are those for solid wires less the constant 0.0153.

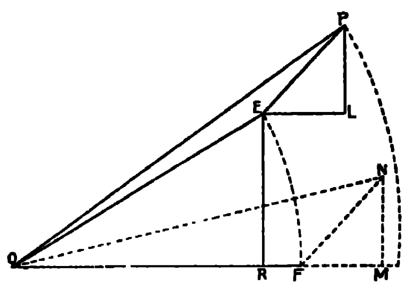


Fig. 1. Relation of Resistance and Inductance to Line Drop

The values for 25 cycles are $\frac{25}{60}$ of those given in Table I, and for any other frequency they are in the ratio of $\frac{\text{frequency}}{60}$. Values for other spacings between conductors may usually be found by interpolation without serious error.

The drop in voltage on a line is affected both by the size and the spacing of the conductors and by the power factor of the load carried by the line. In Fig. 1 the voltage delivered at the end of the line is represented by OE, which is made up of a power component OR and an inductive component ER. Likewise EL represents the ohmic drop and LP the inductive component of the line impedance. The impressed pressure at the generating end is

TABLE I

Re an and Induc e Reactance ng Conduc

'ycles per Second

			Resistance at 68° F. ıms per mile)						ACT mile						
	500 000		0	0.451	0.500	0.535	0.584	0.619	0.647	0.669	0.688	0.703	0.730	0.752	0.771
	350 000	..	0	0.472	0.522	0.556	0.606	0.640	0.668	0.690	0.708	0.724	0.751	0.774	0.792
	300 000		0.	0.482	0.532	0.566	0.615	0.650	0.677	0.699	0.718	0.734	0.760	0.783	0.801
	250 000	....	0	0.493	C.542	0.577	0.626	0.661	0.688	0.711	0.729	0.745	0.772	0.794	0.812
	. ...	0000	0.2583	0.503	0.552	0.587	0.636	0.672	0.698	0.722	0.739	0.755	0.782	0.804	0.822
	...	000	0 3258	0.517	0.566	0.601	0.650	0.685	0.713	0.735	0.754	0.769	0.796	0.818	0.836
	..	00	0.4108	0.531	0.580	0.615	0.664	0.699	0.726	0.748	0.767	0.782	0.810	0.832	0.850
		0	0 518	0.552	0.600	0.636	0.684	0.720	0.746	0.768	0.788	0.804	0.830	0.852	0.871
		1	0 653	0.566	0.614	0.649	0.698	0.734	0.760	0.782	0.802	0.818	0.844	0.866	0.885
Solid		2	0 823	0.580	0.628	0.664	0.712	0.748	0.774	0.796	0.816	0.832	0.858	0.880	0.899
		4	1.30	0.608	0.657	0.692	0.740	0.776	0.803	0.824	0.843	0.860	0.886	0.908	0.927
		6	2.08	0.636	0.684	0.720	0.768	0.804	0.831	0.853	0.872	0.888	0.915	0.936	0.955
		8	3.31	0.663	0.712	0.748	0.796	0.832	0.859	0.880	0.900	0.916	0.943	0.964	0.984

$$OP=\sqrt{(OR+EL)^2+(ER+LP)^2}$$

and the line drop is $OP-OE$.

At 100 per cent power factor there is no inductive component of the load, but MN (LP) is the inductance of the line. The line drop is $ON-OF$, which is less than that at the lower power factor represented by $\frac{OR}{OE}$. The effect of a low power factor on line drop is greatest when the power factor is such that $\frac{OR}{OE}$ equals $\frac{EL}{EP}$. The values of the inductance factor $\frac{ER}{OE}$ for various values of power factor $\frac{OR}{OE}$ are as follows:

Power factor	50	60	70	75	80	85	90	95	100
Inductance factor	86.6	80	71	66	60	53	44	31	0

The calculations for a three-phase line are simplified if they are made for a single-phase line carrying one-half the load, since the size of the conductor required for one-half the load, single-phase, under given conditions, is the same as would be required for the entire load, three-phase.

Examples. 1. What size of conductor is required to carry 6000 kilowatts a distance of 20 miles at 80 per cent power factor, 22,000 volts, 60 cycles three-phase, with a loss of 10 per cent? What will be the line drop at full load with that size of conductor spaced 36 inches apart?

A three-phase line being equivalent to two single-phase lines carrying the same load, the calculation is made for a single-phase line to carry 3000 kilowatts, or 3,000,000 watts, under the given conditions.

In the following calculations I is the line current, R is the line resistance per wire, EL is the resistance component of line drop, LP is the inductive component of line drop, OR is the power component of the delivered pressure, ER is the inductive component of the delivered pressure, and OP is the impressed pressure.

Using the values given

$$I=\frac{3000000}{0.8\times 22000}=170 \text{ amp.}$$

The energy loss may be expressed $\frac{2I^2R}{1000}$, and since it is to be 10 per cent

$$\frac{2I^2R}{1000}=0.10\times 3000=300 \text{ kw., or } 300000 \text{ watts}$$

$$R=\frac{300000}{2\times 170^2}=5.18 \text{ ohms}$$

For 1 mile

$$R=\frac{5.18}{20}=0.259 \text{ ohm}$$

The resistance of No. 0000 wire, Table I, is the nearest to the desired amount, being 0.2583 ohm.

At 170 amperes

$$EL=2\times170\times0.258\times20=1756 \text{ volts}$$

and according to the value given in Table I for No. 0000 wire for 36-inch spacing

$$LP=2\times170\times0.636\times20=4320 \text{ volts}$$

At 22,000 volts

$$OR=0.8\times22000=17600 \text{ volts}$$

$$ER=0.6\times22000=13200 \text{ volts}$$

$$OP=\sqrt{(17600+1760)^2+(13200+4320)^2}=26130 \text{ volts.}$$

The line drop is 26130−22000, or 4130 volts, which equals 18.80 per cent.

2. What will be the line loss and voltage drop on a three-phase 60-cycle line of No. 0 wire having a length of 40 miles at a line pressure of 44,000 volts, with a load of 6000 kilowatts at 90 per cent power factor?

Ans. Line loss=476 kw. Voltage drop=4880 volts, or 11.1%

Mershon Diagram. R. D. Mershon devised a diagram, Fig. 2, by which line drop may be readily calculated on the foregoing principles, the only values required being those for the ohmic and the inductive components of line impedance expressed as percentages of the line pressure. Fig. 2 is based on the principles of Fig. 1, the concentric circles being described about a center (off the page) which corresponds to point O in Fig. 1. The divisions are expressed as percentages, thus being applicable to any line voltage. The use of Fig. 2 may be illustrated with the values in example 1. The resistance component of the No. 0000 line is 1760 volts, which is 8 per cent of the line voltage of 22,000; the inductive component is 4360 volts, or 19.8 per cent.

Follow up the 0.8 power factor line of Fig. 2 to the point where it meets the O circle and then follow to the right 8 divisions (the resistance component) and thence vertically 19.8 divisions (the inductive component), where a point is reached which is just below the 19 per cent circle. This corresponds to point P in Fig. 1, and the drop is 18.8 per cent as found by the calculation.

Assume the load on the circuit to be at 100 per cent power factor; start at the O circle on the base line, pass to the right 8

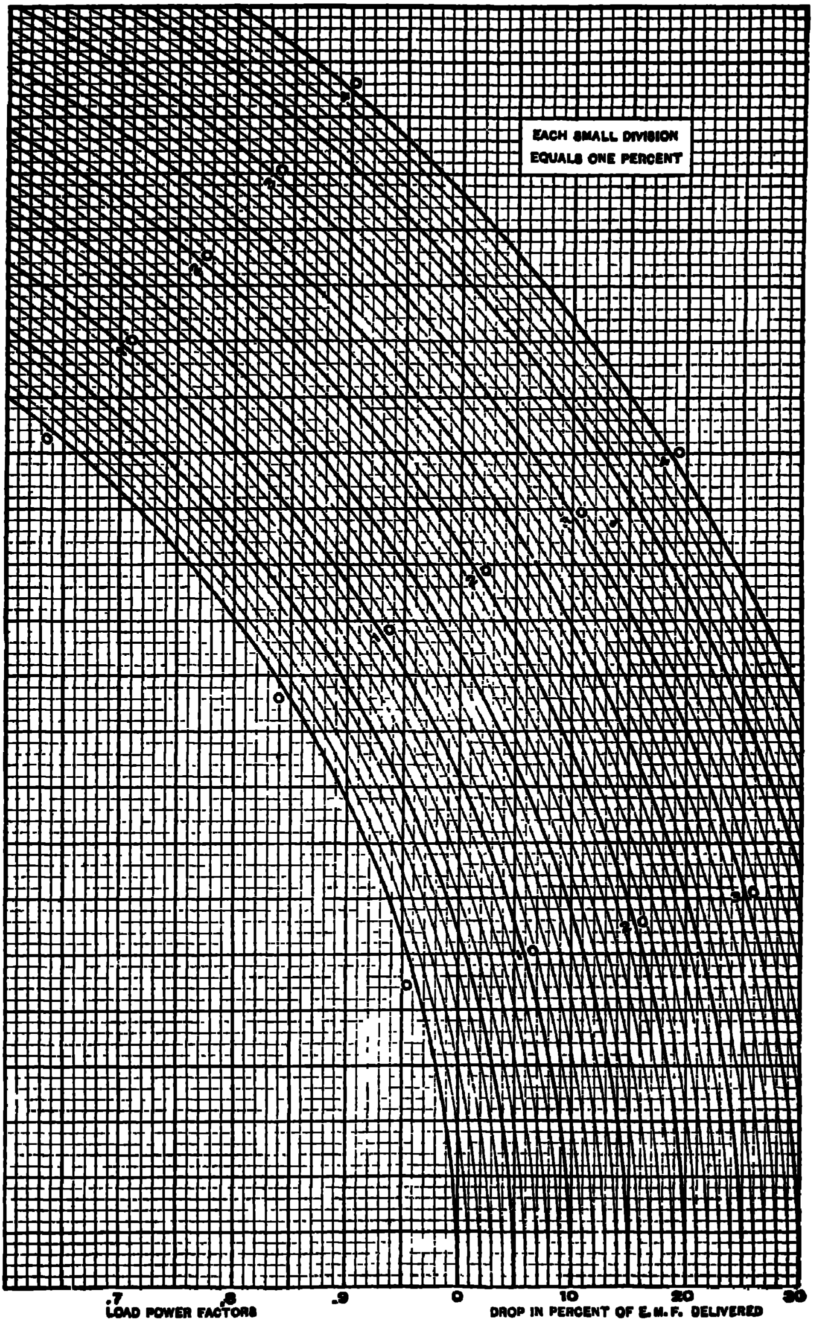


Fig. 2 Mershon Diagram for Line Drop

divisions and thence vertically 19.8 divisions, and the per cent drop is found to be about 9.8, or approximately one-half what it is at 80 per cent power factor. At 60 per cent power factor it is found to be about 20.8 per cent.

With Table I and the Mershon diagram the determination of line drops can be accomplished very speedily after a little practice and with sufficient accuracy for most practical purposes.

HIGH-TENSION FACTORS

Electrostatic Capacity. At the higher voltages and with longer lines the electrostatic capacity of an overhead transmission line becomes an appreciable factor in its design and operation.

The line may take current for charging in such quantity as to absorb a part of the generator and transformer capacity and affect the voltage regulation. The charging current is 90 degrees ahead of the power current and thus has a beneficial effect in offsetting the inductive component of motor load and improving the power factor in many cases. However, the charging current is approximately constant while the pressure is maintained on the line and does not vary as the load current varies from hour to hour during the day. It is therefore necessary, in many cases, to keep some extra generating capacity in operation during the hours when the load is small, and at these times the charging current of the line is equal to or greater than the load current.

At 60 cycles the charging current per mile of line at E kilovolts from phase to neutral is found from the formula

$$I = \frac{6.28 \times fLCE}{10^9}$$

f being frequency, L being length, and C being capacity in microfarads. At 60 cycles, 1000 feet, and 1000 volts

$$I = 0.377\, CE$$

where E is the voltage in kilovolts from phase to neutral.

The value of the capacity C varies with the size and spacing of the conductors. For one mile of line

$$C = \frac{0.03883}{\log\left(\frac{2D}{d}\right)}$$

where D is the distance between centers and d is the diameter of the conductor.

Thus for No. 0 wire spaced 120 inches apart, d being 0.325 inch

$$C=\frac{0.03883}{\log\left(\frac{2\times120}{0.325}\right)}=\frac{0.03883}{2.868}=0.01355 \text{ m.f.}$$

The charging current per mile for a line of No. 0 wire at this spacing and a voltage of 50,000 from phase to neutral (86,600 between phases) would be

$$I=0.377\times0.01355\times50=0.255 \text{ amp.}$$

If the line were 80 miles in length, the total charging current would be

$$I=80\times0.255=20.4 \text{ amp.}$$

The apparent power required to charge the line would be $3\times20.4\times50$, or 3060 kilovolt-amperes, and the line could not be kept alive by a plant of less than 3000 kilovolt-amperes capacity.

The charging current is most conveniently determined by the use of a table arranged to avoid the cumbersome calculation of the values of line capacity. Table II gives the values of charging current per mile, per 100,000 volts, at 60 cycles for three-phase lines. The charging current for No. 0 wire at 120-inch spacing is 0.51 ampere per mile. Hence the charging current for an 80-mile line at 86,600 volts (line pressure) is

$$I=\frac{0.51\times86600\times80}{100000\times1.73}=20.4 \text{ amp.}$$

which is the value previously determined by calculation.

Example. What is the charging current of a 60-cycle line of three No. 0000 conductors 120 miles long, having a spacing of 144 inches between conductors and a voltage of 110,000? What kilovolt-ampere capacity will be required to charge the line at no load?

Ans. Current = 40.7 amperes = 7745 kv.-a.

Effect of Charging Current on Line Drop. The line drop is somewhat reduced by the charging current if the power factor is raised by it, as is the case when an inductive load is carried by

TABLE II

Charging Curren Single per 100,000 Vo om Pha Neu

Cycles per Second)

	A.W G														
[illegible]		1.010	0.896	0.830	0.755	0.709	0.676	653	0.63-	0.615	0.593	0.574	0.560
350 000		0.951	0.851	0.796	0.725	0.681	0.6[illegible]	628	0.61(	0.595	0.575	0.556	0.543
300 000		0.932	0.836	0.780	0.711	0.671	0.641	.619	0.60	0.588	0.568	0.549	0.536
250 000		0.904	0.818	0.765	0.698	0.659	0.631	610	0.59:	0.581	0.559	0.542	0.530
		0.887	0.800	0.749	0.686	0.646	0.620	600	0.58:	0.572	0.549	0.534	0.522
		0.857	0.780	0.730	0.671	0.633	0.608	.590	0.57:	0.562	0.539	0.524	0.514
		0.836	0.760	0.712	0.656	0.620	0.595	.579	0.56:	0.550	0.529	0.514	0.506
	0	0.78:	0.716	0.675	0.624	0.593	0.570	553	0.54(	0.528	0.510	0.497	0.486
	1	0.76:	0.698	0.660	0.611	0.581	0.559	543	0.53(	0.519	0.502	0.488	0.478
	2	0.74:	0.682	0.645	0.598	0.569	0.549	533	0.52(	0.510	0.493	0.480	0.470
Solid	3	.72:	.667	.631	.586	.558	.540	523	.51]	.501	.485	.472	.462
	4	0.70:	0.652	0.618	0.575	0.548	0.529	514	0.50:	0.492	0.477	0.465	0.455
	6	0.67-	0.624	0.592	0.553	0.528	0.510	497	0.48:	0.476	0.462	0.450	0.441
	8	0.64:	0.598	0.569	0.533	0.510	0.493	[illegible]	0.47(	0.461	0.448	0.437	0.429

the line. If the line used in the foregoing discussion carries a load of 15,000 kilowatts at 80 per cent power factor lagging, the current at the receiver end of the line is

$$I=\frac{15\,000\,000\times 1.73}{3\times 86600\times 0.8}=125 \text{ amp.}$$

This current is made up of a power component of 0.8×125, or 100 amperes, and an inductive component of 0.6×125, or 75 amperes. At the generating end the inductive component is reduced by the charging current to $75-20.4$, or 54.6 amperes. The effect of the charging current on the line is the same as if one-half of it flowed the full length of the line, and the average value of the inductive component is therefore $75-10.2$, or 64.8 amperes. Hence the average value of the line current is

$$I=\sqrt{(100)^2+(64.8)^2}=119 \text{ amperes}$$

and the average power factor is $\frac{100}{119}$, or 84 per cent. The line drop may now be found from the Mershon diagram, Fig. 2.

The resistance of each No. 0 wire for 80 miles is 0.5188×80, or 41.5 ohms, and the reactance is 0.83×80, or 66.4 ohms, Table I. The resistance drop is 41.5×119, or 4940 volts, which equals 9.88 per cent of 50,000 volts. The reactance drop is 66.4×119, or 7900 volts, which equals 15.8 per cent of 50,000 volts. In the Mershon diagram, starting at the intersection of the 0.84 power factor line with the O circle, pass to the right 9.88 divisions and thence upward 15.8 divisions, and the drop is found to be 17 per cent.

If there were a negligible charging current on this line, the line current would be 125 amperes. The resistance drop would be 125×41.5, or 5190 volts, which equals 10.4 per cent; and the reactance drop would be 125×66.4, or 8300 volts, which equals 16.5 per cent. Starting at the 0.8 power factor line and the O circle, pass to the right 10.4 divisions and thence vertically 16.5 divisions, and the drop is found to be 18.2 per cent instead of the 17 per cent found with the charging current.

When the line is carrying 40 per cent of its maximum load, or 6000 kilowatts, the load current is 0.4×125, or 50 amperes,

and it may be assumed that the load power factor has dropped to 70.7 per cent. In this case the power and the inductive components of the load are each 50×0.707, or 35.3 amperes. The average line current is

$$I=\sqrt{35.3^2+(35.3-10.2)^2}=43.3 \text{ amp.}$$

and the average line power factor is $\frac{35.3}{43.3}$, or 81.6 per cent. At 20 per cent load, or 3000 kilowatts, and 70.7 per cent power factor the line current is

$$I=\sqrt{17.6^2+(17.6-10.2)^2}=19.2 \text{ amp.}$$

and the line power factor is $\frac{17.6}{19.2}$, or 92 per cent. At lower loads the

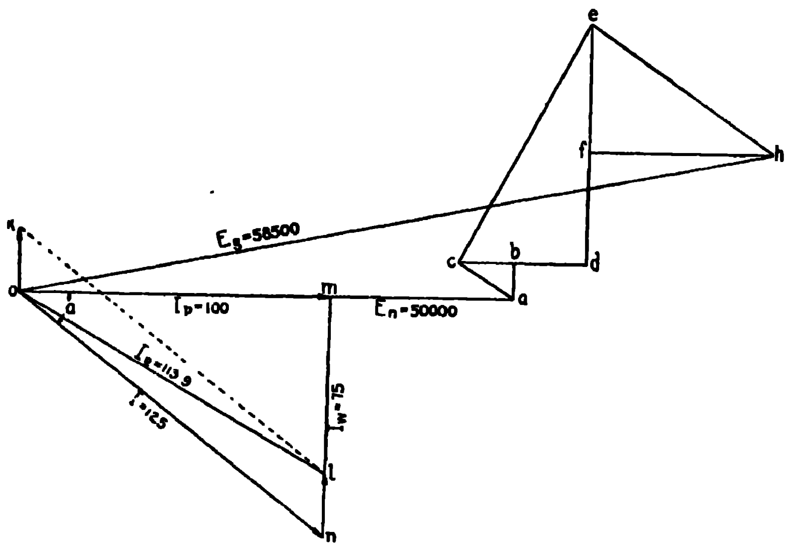


Fig. 3. Vector Solution of Line Regulation

line power factor will increase to 100 per cent and then decrease as it becomes leading instead of lagging.

Example. What will be the voltage drop as found by the use of the Mershon diagram on a line of three No. 00 conductors 70 miles in length, spaced at 84 inches, when carrying a load of 12,000 kilowatts at 70 per cent power factor and at 66,000 volts? What will be the power factor at the generator end at full load and at half load? At what load will the power factor be 100 per cent, if the power factor of the load is 70 per cent?

Ans. Drop=18.5 per cent; P.F. full load .76, half load .81; load at 100 per cent 1615 kw.

Vector Method of Calculating Long-Lihe Problems. The solution of problems in long lines at voltages high enough to make the charging current a factor may be reached more accurately by resolving the currents and voltages into vectors.

In Fig. 3 $E_r = Oa$ is the pressure at the load end of the line; the load current is On; the power component is Om, or $On \cos a$; and the reactive component is mn, or $On \sin a$.

The charging current of the line is represented by Ok, this being 180 degrees ahead of the reactive component mn. The triangle abc represents the voltage drop in the line conductors due to the charging current, ab being the resistance drop, or $\frac{I_c R}{2}$, and bc being the inductive drop, or $-\frac{I_c X}{2}$. The triangle cde represents the voltage drop in the line due to the power component $I \cos a$ of the load current, cd being the ohmic drop $IR \cos a$ and de being the inductive drop $IX \cos a$ in the line wires. The triangle efh represents the voltage drop due to the reactive component $I \sin a$ of the power current, ef being $-IR \sin a$ and fh being $IX \sin a$.

The generator pressure necessary to overcome the net resultant of all these components of drop is $Oh = E_g$.

Examples. 1. In the line used in the preceding sections the voltage E_n equals $\frac{86600}{1.73}$, or 50,000 volts to neutral; the size of conductor is No. 0; the separation is 120 inches; the length, 80 miles; the load, 15,000 kilowatts at 80 per cent power factor; the frequency, 60 cycles; the current I at load end, $I = \frac{15\,000\,000}{3 \times 0.8 \times 50000}$, or 125 amperes; the resistance per mile, Table I, 0.5188 ohm, or 80×0.5188, which equals 41.5 ohms for the line; and the reactance per mile, Table I, 0.83 ohm, or 80×0.83, which equals 66.4 ohms for the line. The charging current per mile per 100,000 volts, Table II, is 0.51 ampere. The charging current at the generator end is

$$I_c = \frac{0.51 \times 80 \times 50000}{100000} = 20.4 \text{ amp.}$$

for the line. The load current is made up of a power component $I \cos a$, which equals 125×0.8, or 100 amperes, and a reactive component $I \sin a$, which equals 125×0.6, or 75 amperes. The charging current neutralizes 20.4 amperes of the reactive component, being in opposition to it, leaving a reactive component of $75 - 20.4$, or 54.6 amperes at the generator end. The current at the generator end is therefore

$$I_g = \sqrt{(100)^2 + (54.6)^2} = 113.9 \text{ amp.}$$

The power factor at the generator is $\frac{100}{113.9}$, or 0.877.

In Fig. 3 the pressure at the load $E_r = 50000$ is Oa and the current I, which equals 125 amperes, is On. The power component $I \cos a$, which equals 125×0.8, or 100 amperes, is Om, and the reactive component $I \sin a$, which equals 125×0.6, or 75 amperes, is mn. The charging current I_c being Ok, the current at the generator is

$$Ol = \sqrt{(Om)^2 + (mn - Ok)^2} = \sqrt{(100)^2 + (75 - 20.4)^2} = 113.9 \text{ amp.}$$

The drop due to the charging current is

$$ab = \frac{I_c R}{2} = \frac{20.4 \times 41.5}{2} = 422$$

and

$$bc = -\frac{I_c X}{2} = -\frac{20.4 \times 66.4}{2} = -677 \text{ volts}$$

The drop due to the power component of the load current is

$$cd = IR \cos a = 125 \times 0.8 \times 41.5 = 4150 \text{ volts}$$

and

$$de = IX \cos a = 125 \times 0.8 \times 66.4 = 6640 \text{ volts}$$

The drop due to the reactive component of the load current is

$$ef = -IR \sin a = -125 \times 0.6 \times 41.5 = -3112 \text{ volts}$$

and

$$fh = IX \sin a = 125 \times 0.6 \times 66.4 = 4980 \text{ volts}$$

The algebraic sum of the components $bc + cd + fh$ is $-677 + 4150 + 4980$, or 8453 volts which is directly opposed to the impressed pressure at the load end. The sum of the components $ab + de + ef$ is $422 + 6640 - 3112$, or 3950 volts which is at right angles to the pressure at the load.
The impressed pressure required at the generator end is

$$E_g = \sqrt{(50000 + 8453)^2 + (3950)^2} = 58580 \text{ volts}$$

The rise in pressure at no load is bc, or 677 volts, and the drop at full load is 8580 volts. The regulation is $8580 + 677$, or 9257 volts, which equals 18.51 per cent. This compares with 17 per cent found by the use of the Mershon diagram. The difference would be still greater at higher voltages.

2. Assume a line 120 miles in length at 110,000 volts, 60 cycles, the loss to be 10 per cent at a full load of 30,000 kilowatts; the power factor at full load to be 80 per cent; and the separation of conductors to be 144 inches. What pressure is required at the generator end to deliver 110,000 volts at the load end at full load; at half load; and at no load?
Ans. Full load 136,350 volts; half load 121,170 volts; no load 116,610 volts

Corona Loss. At voltages above 55,000 with conductors of the smaller sizes there is at times a loss of energy through the air, which is called *corona* loss. It is more pronounced in wet

TABLE III

Disruptive Critical Voltage for Corona Loss

(At Sea Level)

	Size		Diameter (in.)	Spacing (feet)						
	CM	A.W.G.		4	5	6	8	10	12	14
				Voltage between Phase Wires (kilovolts)						
Stranded	500 000		0.818					188	194	199
	350 000		0.679					161	166	170
	300 000		0.620					151	156	161
	250 000		0.590				138	144	149	152
	....	0000	0.530				125	130	135	138
		000	0.470				114	118	121	124
		00	0.420			98	104	108	111	114
Solid		0	0.325			85	89	92	95	97
		1	0.289		75	77	81	83	86	88
		2	0.258		69	70	74	76	78	80
		3	0.229	59	62	64	66	68	70	72
	....	4	0.204	54	56	58	60	62	64	65

weather and at high altitudes and occurs at lower voltages with the smaller sizes of wire than with the larger sizes. The voltage at which energy loss begins is called the *disruptive critical voltage,* and that at which the discharge becomes luminous is called the *visual critical voltage,* the latter being somewhat the higher. The loss of energy varies with the frequency, size and spacing of wire, barometric pressure, and moisture conditions.

The corona loss in kilowatts per mile of three-phase line is

$$P=0.00554\,f\sqrt{\frac{d}{2D}}\,(E-E')^2 \text{ kw.}$$

where f is frequency, d is diameter of the conductor, D is spacing of conductors, and E is line voltage and E' disruptive critical voltage, each in kilovolts. The values of E' are given for various sizes of conductor in Table III.

Example. With a line of No. 00 cables, spaced at 12 feet at a line voltage of 140,000, and a frequency of 60 cycles, what will be the corona loss per 100 miles?

From Table III the value of E′ is 111 kilovolts, d is 0.42 inch, and D is 12×12, or 144 inches.

$$P=0.00554\times60\sqrt{\frac{0.42}{288}}\,(140-111)^2=10.65\text{ kw. per mile}$$

For 100 miles the corona loss will be 100×10.65, or 1065 kilowatts. This is an excessive loss, and it will be necessary to use a larger conductor. An aluminum conductor of equivalent resistance may be used, and it will have an area of $\frac{133000}{0.62}$, or 210,000 circular mils, which is about No. 0000. For a No. 0000 cable the diameter, Table III, is 0.53 inch, and the critical voltage is 135 kilovolts. For this size of cable the loss is therefore

$$P=0.00554\times60\sqrt{\frac{0.53}{288}}\,(140-135)^2=0.355\text{ kw. per mile.}$$

For 100 miles the loss will be 35.5 kilowatts, which is not an excessive amount.

The example just given illustrates the limitation of the use of small conductors at voltages above 100,000, and it is sometimes necessary to augment the diameter of the conductor by using a steel-core cable or a cable of copper-clad conductors. In the case in point it would have been necessary to resort to these devices, if the line had not needed to be as large as No. 00 copper.

It will be seen from the formula just used that it is important to select a conductor large enough so that its critical voltage is not more than 5 to 10 kilovolts below the working voltage. If the critical voltage for the conductor chosen is above the working voltage there is no corona loss.

The critical voltage for altitudes above sea level is obtained from the values of Table III by multiplying them by the following correction factors:

Altitude	Factor	Altitude	Factor
0	1.00	5000	0.82
500	0.98	6000	0.79
1000	0.96	7000	0.765
1500	0.94	8000	0.74
2000	0.92	9000	0.71
2500	0.905	10000	0.68
3000	0.89	12000	0.63
4000	0.86	14000	0.58

Losses determined from the formula given are fair-weather losses. During rain or snow these may be increased to values several times the normal amount, and corona loss may take place at such times in lines which are normally not subject to it.

TABLE IV

Properties of Stranded Aluminum Cables

No. A.W.G.	Bare Diameter (mils)	Area (cir. mils)	Weight (lb.) Per 1000 Feet	Weight (lb.) Per Mile	Weight (lb.) Per 1000 Feet, Weather-Proof	Bare feet per Pound	Resistance at 68° F. (ohms) Per 1000 Feet	Resistance at 68° F. (ohms) Per Mile
....	1.15	1000000	920.0	4858	1108	1.087	0.01695	0.0895
....	1.00	750000	690.0	3645	1067	1.45	0.0226	0.1193
....	0.81	500000	460.0	2430	740	2.04	0.033	0.179
....	0.73	400000	368.0	1944	567	2.72	0.0424	0.224
....	0.68	350000	322.0	1701	502	3.11	0.0484	0.256
....	0.63	300000	276.0	1458	436	3.62	0.0565	0.298
. .	0.58	250000	230.0	1215	375	4.35	0.0678	0.358
0000	0.54	211600	195.0	1028	280	5.73	0.08	0.423
000	0.47	167800	154.0	816	232	6.48	0.101	0.533
00	0.42	133100	122.0	647	192	8.16	0.127	0.673
0	0.37	105500	97.1	513	155	10.3	0.160	0.847
1	0.33	83690	77.0	407	132	13.9	0.202	1.069
2	0.30	66270	61.0	323	108	16.4	0.255	1.35
3	0.26	52630	48.5	256	88	20.6	0.322	1.70
4	0.23	41740	38.5	203	72	26.0	0.406	2.144

SIZES AND KINDS OF CONDUCTORS

ALUMINUM CONDUCTORS

Advantages. In certain cases aluminum has advantages as compared with copper which must be considered. The specific gravity of aluminum is only 30 per cent of that of copper, and for construction in rough country the reduced weight is of material assistance in transportation and erection. The conductivity of aluminum is about 62 per cent of that of copper, so that a part of the saving in weight is offset by the increased cross-section required to give equivalent conductivity. The net result is that for equal resistance the aluminum conductor weighs $\frac{0.30}{0.62}$, or 48.4 per cent, of the copper conductor, thus reducing the dead load on poles and towers quite appreciably. The properties of stranded aluminum cables are given in Table IV.

Physical Characteristics. The temperature coefficient for the resistance of aluminum averages about 0.0021 per degree Fahrenheit. The coefficient of linear expansion is 0.0000128 per degree Fahrenheit between 0° and 100°. The tensile strength varies, as

does that of copper, with the amount of annealing after it is drawn. Hard-drawn aluminum such as is used in making up stranded cables has a strength of 23,000 to 27,000 pounds per square inch. Annealed aluminum is used only for underground cables and the like where flexibility is of more value than tensile strength. Under continued stress permanent elongation takes place, thus tending to increase the sag somewhat after installation.

The use of aluminum for conductors depends largely on the ratio of the cost to the cost of copper. The prices in normal times are approximately equivalent when relative conductivities and weight are considered. The advantage of aluminum therefore lies chiefly in the practical considerations above noted.

IRON AND STEEL AS CONDUCTORS

Limitations. Wire and cable of iron or steel may be used with economy as conductor material for transmission lines under certain conditions. The effective resistance of these materials is, however, about ten times that of copper of equal cross-section, and there are other limitations which must be considered before a decision is made in favor of the use of iron or steel for a.c. transmission. For instance, iron or steel is subject to corrosion, while the life of copper is very long when used without insulating covering on poles. Iron or steel costs about one-fourth as much as copper wire of equal cross-section when copper is 21 cents per pound; this is equivalent to 2.5 times the cost of copper of equal conductivity.

Iron wire is made in grades known as B B. and E.B.B., and steel wire is made in the ordinary grade, Siemens-Martin, and extra strength grades. The wire is used in steel wire gage (or Birmingham wire gage) sizes up to No. 4, and in 7-strand or 19-strand cables of iron or steel in the larger sizes. The cable sizes go by fractions of an inch, as in Table V.

Resistance. The resistance of iron and steel when carrying alternating current varies with the current strength, increasing up to the point of saturation and then decreasing somewhat at higher values of current. It is also dependent on the frequency, the increase being greater at 60 cycles than at 25 cycles.

TABLE V

Iron and Steel Cable Data

Size (in.)	Size of Strands (B.W.G.)	Diameter of Strands (in.)	Diameter of Cable (in.)	Area (cir. mils)
$\frac{1}{4}$	#14	0.083	0.249	48200
$\frac{9}{32}$	#13	0.095	0.285	63200
$\frac{5}{16}$	#12	0.109	0.327	83200
$\frac{3}{8}$	#11	0.120	0.360	100800
$\frac{1}{2}$	#8	0.165	0.495	190600

The variation in the resistance of $\frac{5}{16}$-inch cables of the various grades of iron and steel at 60 cycles is shown by the curves in Fig. 4. The resistance of various sizes of ordinary grade steel

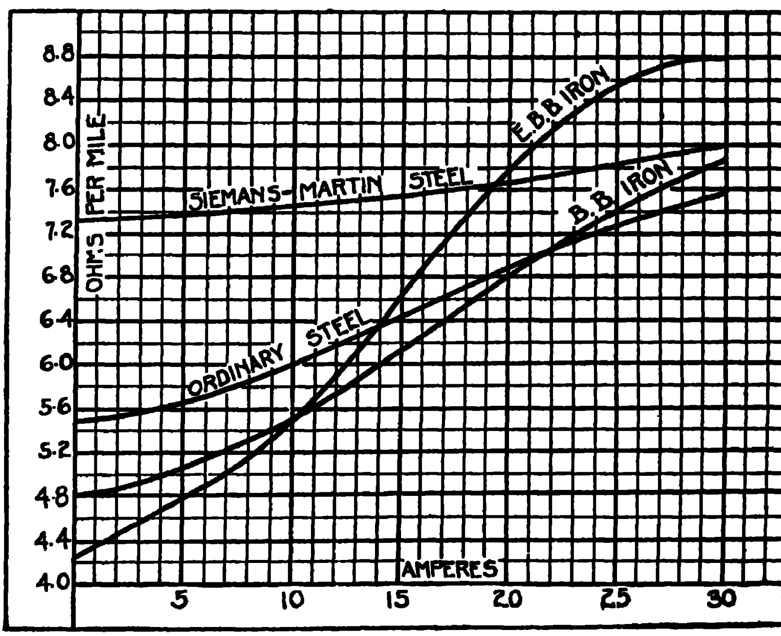


Fig. 4 Resistance per Mile of $\frac{5}{16}$ Iron and Steel Cables

from $\frac{3}{8}$ to $1\frac{1}{4}$ inch, 60 cycles, is shown by the curves in Fig. 5, and the loss in kilowatts at various currents is shown in Fig. 6. The energy loss on a $\frac{5}{16}$-inch cable is 1 kilowatt at 12.5 amperes and 5 kilowatts at 26 amperes, increasing five-fold for a two-fold increase in current.

At 12.5 amperes with $\frac{5}{16}$-inch cable the loss per mile of line is 3 kilowatts, and for a 50-mile line it would be 150 kilowatts. If the line pressure were 50,000 volts and the power factor 80 per cent, the energy component of the line current would be 12.5×0.8, or 10 amperes. The load carried would be $\frac{3\times10\times50000}{1.73\times1000}$, or 866 kilowatts, and with a line loss of 150 kilowatts the loss would be

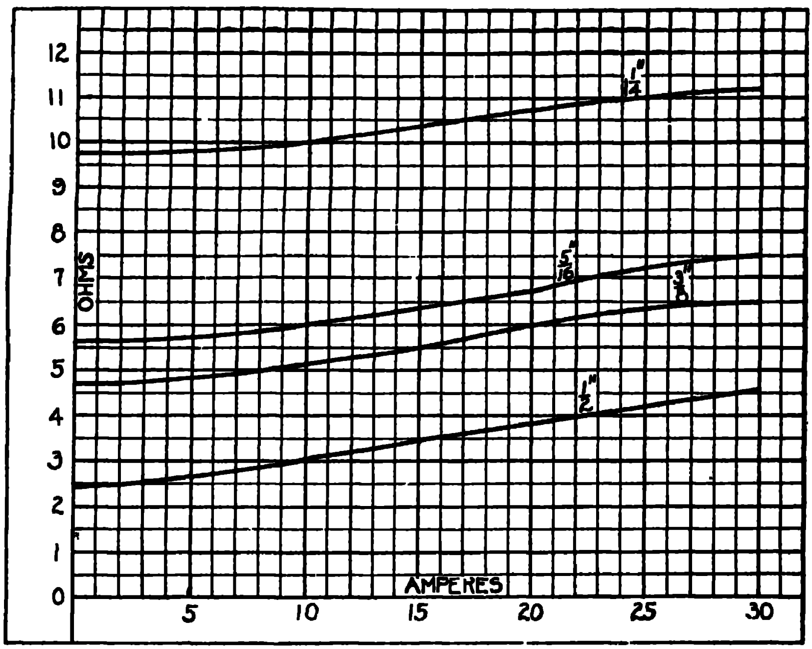


Fig. 5. Resistance per Mile of Stranded Steel Cables, Ordinary Grade

$\frac{150}{866}$, or 17.3 per cent. If the line loss is to be held within 10 per cent, the pressure will have to be made higher, thus reducing the current. The energy loss at 10 per cent being 86 kilowatts, the loss per mile per conductor would be $\frac{86}{3\times50}$, or 0.57 kilowatts. The current at 0.57 kilowatt loss would be about 9.5 amperes, Fig. 6. The line pressure would, therefore, have to be $\frac{12.5}{9.5}\times50000$, or 65790 volts for 10 per cent loss. At higher loads the voltage would have

to be two to three times that required for a copper line giving the same line loss.

The preceding calculations lead to the general fact that the current density should be about 0.1 ampere per 1000 circular mils in steel conductors compared with a density of 1 ampere per 1000 circular mils in copper conductors if the line loss is not to exceed 10 per cent and the line voltage is 1000 volts per mile. For stranded steel conductors of ordinary grade the currents should

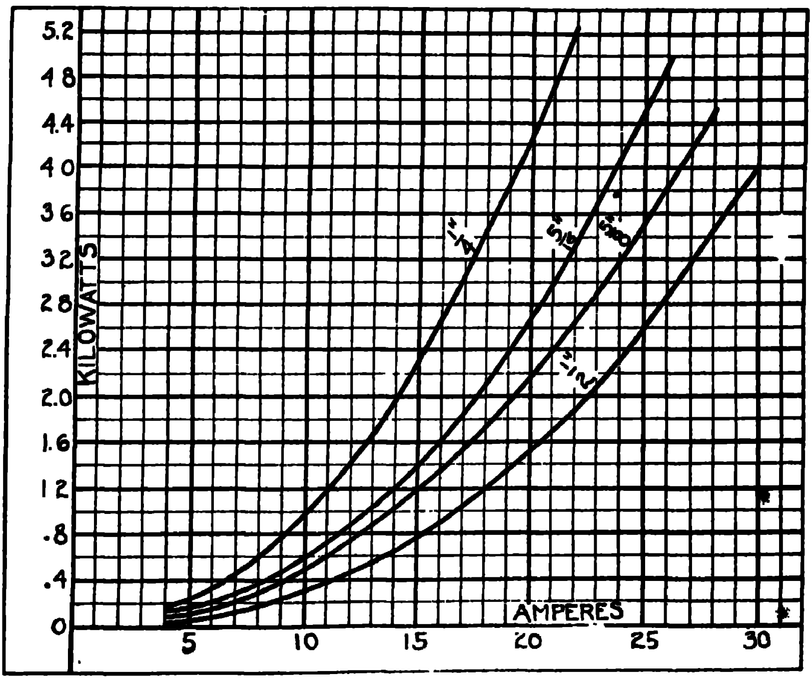


Fig. 6. Energy Loss per Mile per Conductor in Stranded Steel Cables, Ordinary Grade, at Various Current Densities

not greatly exceed the following values: $\frac{1}{4}$-inch, 5 amperes; $\frac{5}{16}$-inch, 8 amperes; $\frac{3}{8}$-inch, 11 amperes; $\frac{1}{2}$-inch, 20 amperes.

The resistance of iron wire of the grades known as B.B. and E.B.B. varies considerably more with current strength than does steel wire. On the other hand, with cables of the steel known as Siemens-Martin, the variation is much smaller than with iron or ordinary grade steel. The initial resistance of B.B. and E.B.B. is somewhat lower than that of ordinary steel, while that of Siemens-

Martin steel is about 25 per cent higher than that of ordinary steel. These relations are evident in the curves of Fig. 4.

Reactance. The magnetic properties of iron and steel give them an internal reactance which varies with the current strength as does the resistance. This reactance is in addition to the external reactance due to the separation of polarities, and the two must be added in calculating line drop. Internal reactance is most conveniently indicated by curves of the same form as used for resistance. The reactance curves of ordinary grade steel are shown in Fig. 7 for the common sizes of stranded cables, and the values of

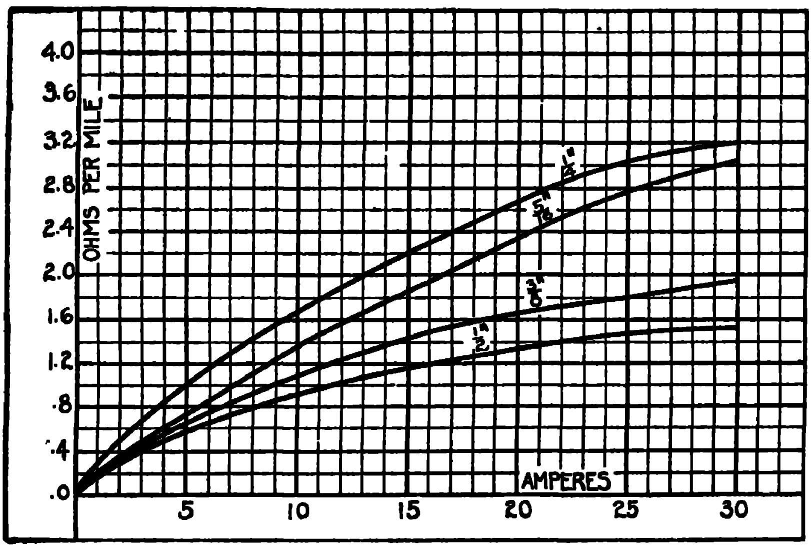


Fig. 7. Internal Reactance per Mile of Stranded Steel Cable

external reactance are given in Table VI. The reactance of a $\frac{5}{16}$-inch steel cable carrying 8 amperes is 1.1 ohms per mile internal, Fig. 7, and 0.66 ohm per mile external at 60-inch separation, Table IV, making a total of 1.76 ohms per mile. From Fig. 5 the resistance per mile at 8 amperes is 5.8 ohms. Hence the resistance drop of a circuit of $\frac{5}{16}$-inch steel carrying 8 amperes is 8×5.8, or 46.4 volts per mile and the inductive drop is 8×1.76, or 14.08 volts. These values are of the same order as those of the sizes of copper wire near No. 10 A.W.G.

The production of iron and steel for conductor purposes has as yet been limited, and the composition and heat treatment

TABLE VI

External Inductive Reactance of Single Conductor Steel Cable

(60 Cycles per Second)

	Size: Nominal Diameter (in.)	Size: B W G	Spacing (inches): 12	18	24	36	48	60	72	84	96	108	120
			External Inductive Reactance (ohms per mile)										
Stranded	$\frac{1}{2}$	.	0.421	0.470	0.505	0.554	0.589	0.616	0.639	0.657	0.673	0.688	0.701
Stranded	$\frac{7}{16}$		0.434	0.483	0.518	0.568	0.599	0.630	0.652	0.670	0.686	0.701	0.710
Stranded	$\frac{3}{8}$		0.460	0.509	0.544	0.593	0.628	0.655	0.678	0.696	0.712	0.726	0.739
Stranded	$\frac{5}{16}$		0.471	0.521	0.555	0.604	0.639	0.667	0.689	0.708	0.723	0.738	0.751
Stranded	$\frac{1}{4}$		0.504	0.554	0.589	0.638	0.672	0.700	0.722	0.740	0.754	0.763	0.781
Solid		4	0.560	0.609	0.644	0.694	0.728	0.755	0.778	0.796	0.814	0.826	0.840

TABLE VII

Charging Current in a Single Steel Cable per 100,000 Volts from Phase Wire to Neutral

(60 Cycles per Second)

	Size: Nominal Diameter (in.)	Size: B W G	Spacing (inches): 12	18	24	36	48	60	72	84	96	108	120
			Charging Current (amperes per mile)										
Stranded	$\frac{1}{2}$		1.041	0.925	0.858	0.775	0.730	0.695	0.67	0.65	0.634	0.621	0.609
Stranded	$\frac{7}{16}$	.	0.948	0.853	0.783	0.724	0.681	0.652	0.63	0.618	0.598	0.586	0.574
Stranded	$\frac{3}{8}$	.	0.83	0.755	0.708	0.652	0.618	0.593	0.574	0.560	0.548	0.537	0.528
Stranded	$\frac{5}{16}$	.	0.772	0.706	0.665	0.615	0.584	0.563	0.546	0.533	0.522	0.512	0.504
Stranded	$\frac{1}{4}$	...	0.72	0.662	0.627	0.582	0.555	0.535	0.520	0.508	0.497	0.489	0.482
Solid	...	4	0.730	0.673	0.635	0.590	0.562	0.542	0.526	0.514	0.503	0.496	0.487

which will give the best results have not been standardized. The values given in the foregoing sections for resistance and internal reactance are taken from data derived from tests the results of which were published prior to the year 1919. These tests were made by the U.S. Bureau of Standards, by manufacturers, and by some of the state universities. There is, of course, some variation in the data of different observers, largely on account of differences in the commercial product tested, and the data here given represent a fair average of the values found.

Charging Current. The permissible current density in steel cables being low, the charging current is an appreciable factor and may exceed the component of current due to the load in lines 50 miles or more in length.

In Table VII are given the values of charging current per mile per 100,000 volts (phase to neutral) at 60 cycles. The charging current for a line of $\frac{5}{16}$-inch cables spaced at 60 inches is 0.563 ampere per 100,000 volts. At 66,000 volts and 50 miles, the charging current would be $0.563 \times 50 \times 0.66$, or 18.7 amperes. If the load current were 10 amperes at 80 per cent power factor lagging, the line current at the station end would be

$$I=\sqrt{(8)^2+(18.7-6)^2}=15 \text{ amp.}$$

with a leading power factor of $\frac{8}{15}$, or 53.3 per cent.

Thus the step-up transformers would have to be of a size to take care of about twice the load, and extra generating capacity would also be required if there were no other load on the station to offset the charging current. This factor must therefore be taken fully into account in choosing the type of conductor.

Example. A town having a probable load of 100 kilowatts at 90 per cent power factor is to be supplied from a station located 25 miles away. It is proposed to supply this load by a branch from an existing 22,000-volt system, using stranded steel cable. What size cable should be used for a three-phase line if the loss is limited to 10 per cent? What kilovolt-ampere capacity will be required to supply the charging current, assuming the spacing of conductors to be 48 inches? What will be the voltage drop at full load?

Ans. $\frac{1}{4}$-inch steel or #4 iron; 50-kv.-a. to charge line; drop 10.2 per cent

Durability. The life of galvanized iron and steel varies considerably with the environment. In the vicinity of plants which

give off corrosive vapors or at a railroad crossing it may not last more than a few years. In the ordinary atmosphere of a manufacturing city it is corroded beyond the point of safety in five to ten years, while in the country away from smoke and gases it may last fifteen to twenty-five years. These influences must be considered before the use of steel conductors is decided upon, as the cost of frequent replacement may offset the saving in first cost made by the use of the cheaper metal as a conductor.

Comparative Cost of Steel and Copper Lines. Assume a line of three $\frac{5}{16}$-inch steel cables, costing \$70 per mile of conductor, or \$210 per mile of line, compared with three No. 6 copper wires at 30 cents a pound, or 1260×0.30, which equals \$378 per mile of line. At 5 cents per pound for labor of erection the cost of the conductors is

Copper wire	\$378
Labor	63
Total	\$441 per mile

Steel cables	\$210
Labor	130
Total	\$340 per mile

Assuming a life of sixteen years before the line must be replaced, the depreciation is 6 per cent per annum, which with interest at 6 per cent makes fixed charges of 12 per cent. On the steel line the fixed charges would amount to \$40.80 per annum. With the copper line there would be salvage at about 10 cents per pound at the end of sixteen years, making the net investment to be depreciated \$315. At 12 per cent the fixed charges on this would be \$37.80 per year, a saving of \$3 per mile per year. There would be a further saving in energy loss, which would depend on the load factor and the cost of energy. The balance would be still more in favor of the use of copper if the conditions were such that the replacement of the line had to be made at the end of ten years instead of sixteen, if the price of copper were below 20 cents per pound instead of 30 cents as assumed, or if the conditions were such that No. 8 copper could be safely used.

In general, it may be borne in mind that iron and steel are economical as a substitute for copper or aluminum only in case the length, load, and voltage are such that the line loss with a

copper line would be less than 5 per cent, and a larger size of copper is necessary for mechanical strength than would be necessary for line drop and efficiency. There are comparatively few cases where the use of iron or steel is economical when copper is below 20 cents per pound.

Copper-Clad Steel. The comparatively wide gap between the conductivities of copper and steel and the advantages of strength in favor of steel led to the development of wire made with a steel core and a copper surface known as copper-clad wire. In the best processes the steel and copper are welded, thus checking any tendency for the copper to scale off and permit corrosion to take place. The steel rod is placed inside a copper tube, welded by special processes, and then drawn into the desired sizes of copper-clad wire. By varying the thickness of the copper the conductivity of the finished product may be controlled within certain limits.

The manufacturers have standardized two qualities having conductivities, respectively, 30 per cent and 40 per cent of that of a solid copper conductor. This gives a conductor of high strength, intermediate conductivity, and much longer life than galvanized iron or steel. Greater care in handling is required as the copper is thin and scratches may be deep enough to permit corrosion.

The general properties of 30 per cent copper-clad wire as manufactured by the Standard Underground Cable Company appear in Table VIII. The values of 40 per cent wire are proportionally less as to resistance and about 5 per cent lower in breaking weight.

With a No. 3 copper-clad conductor carrying 15 amperes at 33,000 volts the resistance per mile is 5.28×0.6443 (Table VIII), or 3.4 ohms, and the ohmic loss is 15×3.4, or 51 volts per mile. For a 30-mile line the value of IR is 30×51, or 1530 volts, which equals $\frac{1530}{19000}$, or 8 per cent.

There are no published values of inductance of copper-clad wires, but as the area of the steel core is about 78 per cent of the total area, the inductance may be taken as approximately that of the size of conductor next smaller, which would be for No. 4 steel in this case.. The internal reactance of No. 4 steel being about 1.1

TABLE VIII

Comparative Properties of 30 per cent Copper-Clad Steel and Hard-Drawn Copper Wires

Size A.W.G. Gage	Average Resistance per 1000 Feet at 60° F (ohms)		Weight per 1000 Feet (lb.)		Average Breaking Weight (lb.)	
	C.C. Steel	H.D. Copper	C.C. Steel	H.D. Copper	C.C. Steel	H.D. Copper
0000	0.1603	0.04906	584.0	641.0	9875	7914
000	0.2021	0.06189	463.0	509.0	8250	6533
00	0.2549	0.07803	366.0	403.0	6830	5365
0	0.3214	0.09831	291.0	320.0	5680	4386
1	0.4052	0.1241	230.0	253.0	4800	3565
2	0.5110	0.1565	184.0	202.0	3900	2892
3	0.6443	0.1972	145.0	159.0	3200	2338
4	0.8124	0.2488	114.5	126.0	2630	1890
5	1.025	0.3138	91.0	100.0	2160	1520
6	1.292	0.3955	72.0	79.0	1770	1221
7	1.629	0.4986	57.7	61.0	1450	984
8	2.054	0.6288	45.5	50.0	1180	788
9	2.590	0.7934	35.5	39.0	965	630
10	3.267	0.9996	29.0	32.0	790	506
11	4.118	1.262	22.8	23.5	645	403
12	5.195	1.591	18.2	20.0	525	318

ohms and the external reactance (Table VI) being 0.75 at 60 inches, the total reactance per mile is 1.85 and the reactive drop is 15×1.85, or 27.7 ohms. For 30 miles the value of X is 30×27.7, or 831 volts, which equals $\frac{831}{19000}$, or 4.4 per cent.

The charging current would be the same as for a No. 3 copper conductor since the diameters are the same. This may be calculated from the values in Table II. At a spacing of 60 inches the charging current for No. 3 wire is 0.54 amperes per 100,000 volts per mile. At 33,000 volts (19,000 volts to neutral) the charging current of a 30-mile line would be $30 \times 0.19 \times 0.54$, or 3.08 amperes.

As the load current is 15 amperes, this would not be a serious value of charging current. With greater distances and higher voltages, the charging current would be sufficient to be a factor in determining transformer capacity and perhaps generator capacity.

LINE CONSTRUCTION

LINE CHARACTERISTICS

General Features. The electrical characteristics of a transmission line having been determined by calculation, it remains to carry out the design and construction of the physical structures by which the electrical transmission is to be consummated. This involves questions of mechanical and civil engineering which are sometimes of more than minor consequence.

The conductors are commonly suspended on poles or towers, with span lengths to be determined, tension and sag to be reckoned, and the stresses of wind and ice loading to be provided for. This in turn involves the design of pole or tower structures of such strength as will carry the loads imposed upon them under the varying conditions of actual service in all kinds of weather. Thus the design of the line proceeds in the reverse order from its construction, and the questions relating to conductors and insulators will be considered before taking up the design of supporting structures.

The character of the construction is fixed very largely by the working voltage and by the amount of power to be carried. The higher the voltage the greater must be the spacings; and the greater the power the heavier must be the weight of conductors to be carried. Both these factors have a material influence on the character of the supporting structures and on the length of spans.

With lines at voltages below 50,000 the conditions are usually such as permit the use of poles and crossarms of wood with pin-type insulators. The cost of the insulator equipment is moderate, and there is no great advantage in using spans averaging over 250 feet. If longer spans than this are used to save poles, they must be higher in order to give clearance for the line wires above ground, and this largely offsets the saving in the number of poles per mile. Lines at higher voltages require insulators and steel towers the cost of which is relatively much higher than that of the wood-pole equipment, and there is an advantage in spans of greater length. The longer spans require towers of greater height and strength, but a minimum cost per mile is reached with tower lines when the span lengths are 500 to 600 feet.

In mountainous country span lengths are likely to be fixed by topographical conditions, it often being necessary to carry a line from peak to peak touching the higher points and making spans of 1000 to 2000 feet. In such cases each span must be worked out to conform to the topography and the line can usually be so carried that there is ample sag to keep the tension within reasonable limits. Towers are placed at points where the sag would not otherwise permit clearance from intermediate points of prominence.

Sag and Tension. The sag and the tension of a wire between two points of support are calculated by the following formula, which while not rigidly accurate is sufficiently so for the purpose of calculating these values for transmission-line conductors:

$$S = \frac{D^2W}{8T} \text{ ft.}$$

in which S is sag, D is the length in feet of the span, W is the weight in pounds per foot of the conductor (with insulation or ice loading, if any), and T is the tension in pounds. By this formula the sag may be calculated for any assumed value of tension; or, by interchanging S and T in the formula, the value of tension may be found for any assumed value of sag.

Example. With No. 4 wire (bare) and a span length of 200 feet, what will be the sag when the tension is 300 pounds?

The weight of a foot of No. 4 wire is 0.1264 pound and therefore

$$S = \frac{200^2 \times 0.1264}{8 \times 300} = 2.1 \text{ ft.}$$

For a span of 400 feet, other conditions being the same

$$S = \frac{400^2 \times 0.1264}{8 \times 300} = 8.42 \text{ ft.}$$

Thus it is evident that the length of the span is the most important factor in determining the sag and the tension of wires. These vary in direct proportion to the weight of the wire, so that for a No. 1 wire, which has twice the weight of a No. 4, the tension for a sag of 2 feet would be 600 pounds instead of 300 pounds; or, if the tension were left the same, the sag would be 4 feet instead of 2 feet.

Ice and Wind Loading. With long spans (over 500 feet) in a climate subject to sleet storms and high winds the tension must usually be made so high for a proper value of sag that care must be taken not to exceed the breaking strength of the wire. In many parts of the United States sleet has been known to form on wires to a considerable thickness, adding to the load to be carried by the wire an amount considerably in excess of its own weight. To this there may be added the force of the wind, which, while acting laterally, deflects the span and adds a component of load which is appreciable.

It is a very rare occurrence to have a high wind at the same time that there is sleet on the wires, but it is customary to

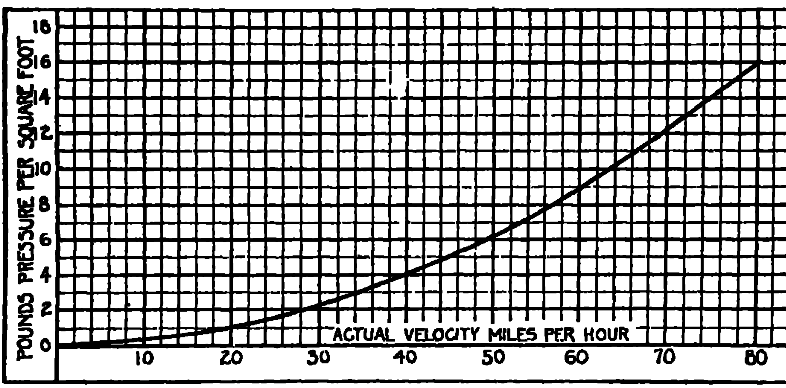


Fig. 8. Relation of Wind Velocity to Pressure

assume a loading of $\frac{1}{2}$ inch of ice (radial thickness) and a wind pressure of 8 pounds per square foot. This corresponds to a wind velocity of 75 miles per hour as recorded by the Weather Bureau. It is, however, not so rare to have more than $\frac{1}{2}$ inch of ice, and these limits are considered ample to take care of lines in case the ice should be more than $\frac{1}{2}$ inch in thickness without a high wind pressure.

The wind velocities as reported by the Weather Bureau are usually taken from points much higher above the surface than the wires of a transmission line are carried, and it is therefore necessary to apply a correction factor to wind velocities taken from Weather-Bureau records in using them for the determination of

wind pressures. The actual values of velocity for the indicated values in weather records are as follows:

Indicated velocity (miles)	30	40	50	60	70	80	90	100
Actual velocity (miles)	26	33	41	48	55	62	69	76

The pressure exerted on wires and structures may be calculated from the formula

$$P = 0.0025\ V^2$$

in which P is pressure in pounds per square foot and V is the *actual* velocity corresponding to the indicated velocity of Weather-Bureau records. For cylindrical objects, such as conductors, the area exposed is calculated from the diameter of the conductor. The curve in Fig. 8 gives the values of pressure in pounds per square foot for various *actual* wind velocities met with in practice.

In the calculation of the unit weight of a conductor loaded with ice and subject to wind, the weight as found for metal and ice must be increased by an amount determined as follows: The loading of the conductor is the resultant of the vertical force of gravity due to the weight and a horizontal force due to the wind as shown in Fig. 9. Thus if the weight is W and the wind pressure is P, the resultant force is $\sqrt{W^2+P^2}$. The weight of ice may be taken as 0.033 pound per cubic inch.

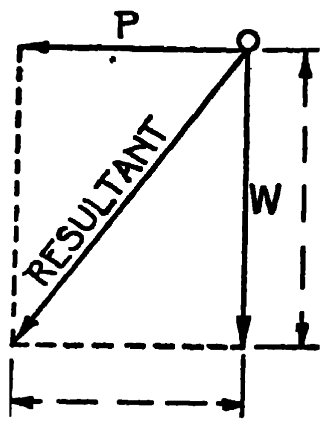


Fig. 9 Resultant Load from Wind Pressure and Weight of Conductor

Effect of Expansion on Sag. The expansion and contraction of a conductor with variation of temperature affects the length of the conductor and this has a material effect on the sag. The length of a copper conductor varies with the temperature according to the formula

$$l_t = l_m\ (1+0.0000096t)\ \text{ft.}$$

in which l_m is the length at the minimum temperature, and l_t the length at t degrees rise. For aluminum the constant is 0.0000128.

and for steel 0.0000064. The length of wire l in a span of length D with a sag S is

$$l = D + \frac{8S^2}{3D} \text{ ft.}$$

Or if the length is known, the sag at the known length is

$$S = \sqrt{\frac{3D\,(l-D)}{8}} \text{ ft.}$$

These formulas give correct results for conductors which do not stretch when carried on rigid supports, but there is sufficient elasticity in transmission conductors and towers to materially modify them in most cases; for instance, the breaking of wires during very cold weather is occasionally met with, but it would be a very common occurrence with lines erected in mild weather if there were not a considerable amount of elasticity. For this reason the factors of safety used in the design of transmission structures are much lower than is safe in most engineering practice. The stretch of a copper wire is $\frac{LT}{AE}$ feet, in which L is the length, T is the tension in pounds, A is the area of the conductor in square inches, and E is the modulus of elasticity. The modulus for annealed copper is 12,000,000; for hard copper 16,000,000; and for aluminum 9,000,000.

Example. Assuming a line of No. 0000 stranded cable to be strung with a 600-foot span, what is the minimum allowable sag under winter conditions; the maximum sag under summer conditions; and how is it determined at what sag the wire should be strung at usual working temperatures?

The method of procedure is to assume that when the conductor is loaded with ice and subjected to wind pressure at the lowest temperature which it will experience, the tension will be equal to the maximum amount to which the conductor may be safely subjected. The first step is therefore to find the sag at the maximum safe tension with ice and wind loading and the length of conductor at this sag. Next assume all load, including the tension of the unloaded conductor, removed, and find the amount by which the length is reduced thereby. Then calculate the sag for the conductor without wind or ice loading at tensions assumed below the safe tension, choosing points well distributed through this range and using the formula

$$S = \frac{D^2W}{8T}$$

These points are plotted in a curve such as that shown in Fig. 10 at AB.

From the length of conductor entirely unloaded, find the lengths of this conductor when subject to the values of tension assumed in getting data for curve AB. Substitute these lengths in the formula for sag based on length and get the corresponding values of sag. Plot these in a curve CD crossing the sag-tension curve AB previously made, and the crossing point will give the tension and the sag of the conductor with the ice and wind loading removed but with the temperature still at the minimum values.

Find the length of the unloaded conductor at maximum temperature by applying the temperature coefficient to the length at minimum temperature.

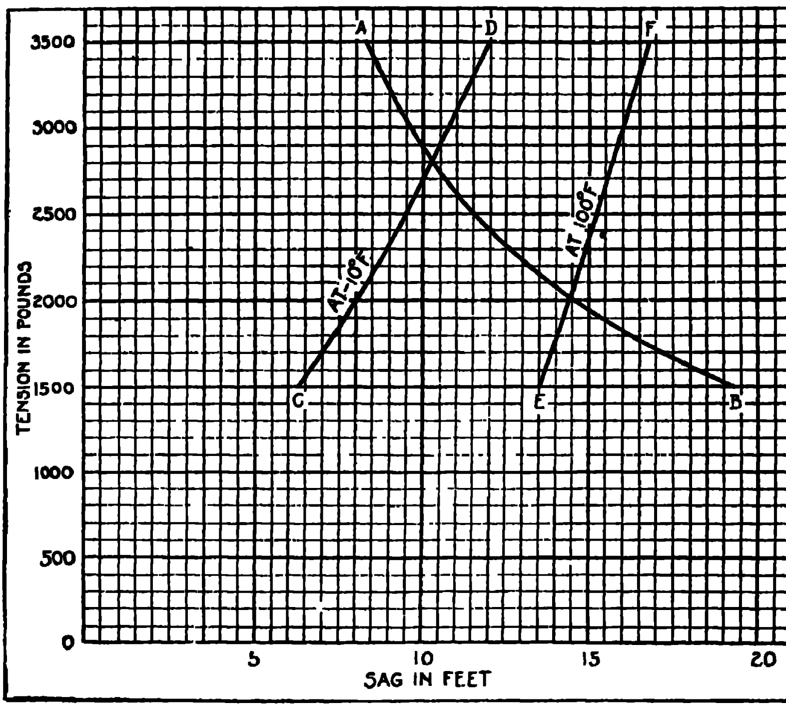


Fig. 10. Determination of Allowable Sag and Tension

The lengths at various tensions and the sags at these tensions are then calculated and plotted in EF, the intersection of the curves EF and AB being the sag and the tension at the maximum temperature without ice or wind loading.

In a similar manner the sag and tension at intermediate temperatures may be obtained. Such figures are needed by the construction force as a guide to the sag which should be allowed in spans of various lengths and at various temperatures.

In the case of the 600-foot span of stranded No. 0000 cable assumed, the calculation is as follows: From Table IX the load per foot with ½ inch of ice and an 8-pound wind pressure is 1.641 pounds. The allowable tension

TABLE IX

Strength and Loading of Conductors

	Size: CM	Size: A.W.G.	Diameter (in.)	Area square inch	Hard-Drawn: Ultimate Tension (lb.)	Hard-Drawn: Allowable Tension (lb.)	Annealed: Ultimate Tension (lb.)	Annealed: Allowable Tension (lb.)	Vertical Load: Dead (lb.)	Vertical Load: ½-Inch Ice (lb.)	Horizontal Load 8-Pound Wind, ½-Inch Ice (lb.)	Resultant Load 8-Pound Wind, ½-Inch Ice (lb.)
Stranded	500 000	. .	0.819	0.3924	23540	11750	13340	6650	1.525	2.345	1.213	2.640
	350 000	. . .	0.679	0.2750	16500	8250	9350	4650	1.068	1.801	1.119	2.120
	.....	0000	0.530	0.1662	9970	5000	5650	2800	0.645	1.286	1.020	1.641
	....	000	0.470	0.1318	7910	3950	4480	2250	0.513	1.116	0.980	1.485
	....	00	0.420	0.1045	6270	3150	3555	1750	0.406	0.978	0.947	1.361
Solid	....	0	0.325	0.0829	4560	2300	2820	1400	0.320	0.833	0.883	1.214
	....	1	0.289	0.0657	3740	1850	2235	1100	0.253	0.744	0.860	1.137
	....	2	0.258	0.0521	3120	1550	1770	900	0.202	0.673	0.838	1.075
	......	3	0.229	0.0413	2480	1250	1405	700	0.159	0.613	0.820	1.024
	....	4	0.204	0.0328	1960	1000	1115	550	0.126	0.564	0.803	0.981
	....	5	0.182	0.0260	1560	800	885	450	0.100	0.524	0.788	0.946
	....	6	0.162	0.0206	1240	600	700	350	0.079	0.491	0.775	0.917

on the cable is 5000 pounds, and the sag at the assumed minimum temperature of $-10°$ F. with the assumed loading must not be less than

$$S=\frac{600^2\times 1.641}{8\times 5000}=14.77 \text{ ft.}$$

With the sag the length of cable l in the span is

$$l=600+\frac{8\times 14.77^2}{3\times 600}=600.97 \text{ ft.}$$

Applying the formula for the stretch of a copper wire, this length would be reduced, if all load, including the tension of the line, were removed, to

$$l_1=600.97-\frac{600.97T}{AE}=600.97-\frac{600.97\times 5000}{0.1662\times 16000000}=599.84 \text{ ft.}$$

in which 0.1662 is the area of the cable and 16,000,000 is the modulus for hard-drawn wire.

The data from which the sag-tension curve AB, Fig. 10, is plotted is based on the weight per foot of bare conductor without wind and ice loading, which is 0.645 pound. Thus for 1500 pounds tension and the given span of 600 feet the sag is

$$S=\frac{600^2\times 0.645}{8\times 1500}=19.3 \text{ ft.}$$

The different values are

Tension (lb.)	1500	2000	2500	3000	3500
Sag (ft.)	19.3	14.5	11.6	9.66	8.3

Applying the formula for the stretch of a copper wire, the length of the 599.84-foot piece of conductor l_1 when stressed at 1500 pounds at $-10°$ F. is

$$l_2=599.84+\frac{599.84\times 1500}{0.1662\times 16000000}=599.84+0.338=600.178 \text{ ft.}$$

In a similar way the values of length at the other assumed tensions are found, and the sag for those lengths is determined from the equation

$$S=\sqrt{\frac{3D\,(l-D)}{8}}$$

At 1500 pounds tension the span D is 600 feet and the length l_2 is 600.178 feet; therefore

$$S=\sqrt{\frac{3\times 600\,(600.178-600)}{8}}=\sqrt{225\times 0.178}=\sqrt{40.05}=6.32 \text{ ft.}$$

At other tensions the lengths and sags are

Tension (lb.)	1500	2000	2500	3000	3500
Length (ft.)	600.178	600.291	600.404	600.576	600.63
Sag (ft.)	6.32	8.1	9.54	10.75	11.9

When plotted, the various values of sag make the curve CD in Fig. 10. The AB and CD curves intersect at approximately 2830 pounds and 10.25 feet; these are the tension and the sag at $-10°$ F. without ice or wind loading.

If the maximum temperature is taken at 100° F., the length of the unstressed wire at that temperature is

$$l_t = 599.84\ (1+[0.0000096\times110]) = 600.473\ \text{ft}.$$

At 1500 pounds the length is

$$l_s = 600.473+\frac{600.473\times1500}{0.1662\times16000000} = 600.473+0.338 = 600.811\ \text{ft}.$$

The sag in the conductor at 1500 pounds is

$$S=\sqrt{\frac{3\times600\ (600.811-600)}{8}}=\sqrt{225\times0.811}=\sqrt{182}=13.5\ \text{ft}.$$

At other tensions the lengths and sags are

Tension (lb.)	1500	2000	2500	3000	3500
Length (ft.)	600.811	600.924	601.037	601.150	601.263
Sag (ft.)	13.5	14.4	15.2	16.0	16.8

Plotting the values of sag, the curve EF is seen to intersect the AB curve at about 2000 pounds and 14.4 feet, the tension and sag respectively at 100° F. without ice or wind loading.

If this calculation is carried through for various temperatures, such as 40°, 50°, 60°, 70°, 80°, and 90° Fahrenheit, and the points of intersection with the AB curve obtained, the data will be at hand for instructions to line foremen as to the sag to be used at various temperatures in erecting the line.

Spans with Supports at Different Levels. The previous discussion of the calculation of sag and stress is based on the assump-

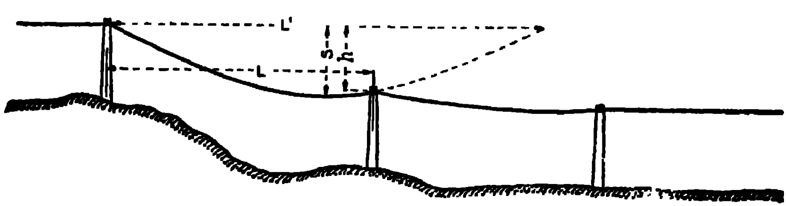


Fig. 11. Spans with Supports at Different Levels

tion that the spans are on level supports. In many cases there is considerable difference between the levels of supports of spans, and with long spans this difference must be taken into consideration.

In Fig. 11 there is shown a span of this sort where the line passes from a higher to a lower level in a single span, while Fig. 12 shows the condition where the change in level extends through two or more spans. In these cases the method of treatment is to consider the span as part of an equivalent longer one having level supports.

The length of the equivalent span D_1, is found by the equation

$$D_1 = \frac{2D\sqrt{S}}{\sqrt{S-h}+\sqrt{S}}$$

in which S is the sag of the equivalent span, D is the length of the actual span (measured horizontally), and h is the difference in level of the ends of the actual span. If a span having a horizontal length of 500 feet has one support 30 feet below the other, and a sag of 36 feet below the higher support is permissible, the length of the equivalent level span would be

$$D_1 = \frac{2\times500\times\sqrt{36}}{\sqrt{36-30}+\sqrt{36}} = 710 \text{ ft.}$$

If the conductor were a No. 0000 stranded cable, the tension at 36 feet sag, without ice or wind loading, would be

$$T = \frac{D^2W}{8S} = \frac{710^2\times0.645}{8\times36} = 1130 \text{ lb.}$$

at the higher end. If ice and wind loading are to be considered, the sag and the tension may be determined for the various con-

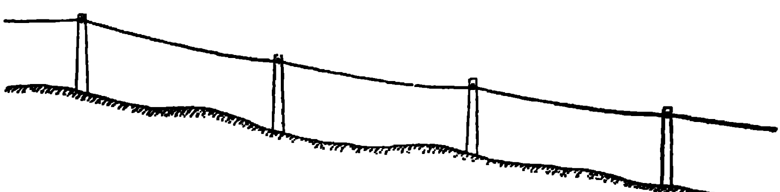


Fig. 12 Spans in Sloping Ground

ditions of temperature for the equivalent span according to the method used in the example previously given. These values then apply to the actual span, except for a small percentage of error for spans having a sag of over 15 per cent.

In case the allowable sag is not known, the length of the level span may be computed from the tension and the weight of conductor. In such a case

$$D_1 = D + \frac{2hT}{WD} \text{ ft.}$$

Thus, with the span of 500 feet of No. 0000 assumed above, the length is

$$D_1 = 500 + \frac{2\times30\times1130}{0.645\times500} = 710 \text{ ft.}$$

In the case of a line passing down a slope, Fig. 12, it is possible to have the sag such that there will be an upward pull on certain supports. This will be true when the difference in level of the supports is greater than the sag of an equivalent level span; for instance, a difference in level of supports of 30 feet requires sag of the equivalent level span of not less than 30 feet.

Sag and tension calculations can often be facilitated by the use of charts in which the values for various lengths of span are plotted in the form of curves.

Example. A line of 350,000 circular mils stranded cables is to be carried on supports spaced 600 feet apart on level ground and having certain spans 800 feet in length where there is a difference of 40 feet in the elevation of the supports. If the temperature at the time of erection of the cable is 70° F., the maximum temperature is 100° F. and the conductor may be loaded with ½ inch of ice radial thickness at a temperature of −10° F. while there is a wind pressure of 8 pounds per square foot acting at right angles to the line, what should be the sag and the tension of the cable at the temperature at which it is erected, in the 600-foot span; in the 800-foot span?

Ans. At 600 ft., sag = 10.8 ft., tension = 4500 lbs.;
at 800 ft., sag = 15.2 ft., tension = 4200 lbs.

LINE INSULATORS

Relative Value of Glass and Porcelain. The continuity of service given over a transmission line is, perhaps, dependent more on the quality and durability of its line insulators than on any other element of line construction. The insulator must be of a material which will stand up under rises of potential and changes of temperature and will withstand the action of the elements.

Glass has some of the desired qualities but is lacking in strength when made in the large sizes needed for the higher voltages.

Porcelain is the most commonly used material as it stands change in temperature and has good mechanical strength. It is dependent for its insulating qualities, to a considerable extent, on its glaze. The firing process, by which this glaze is applied, does not give uniform results, however, and it is necessary to inspect each piece before it is accepted for use as part of a line insulator and to test the assembled parts after completion. Porcelain insulators are more reliable if constructed in parts and cemented together after burning.

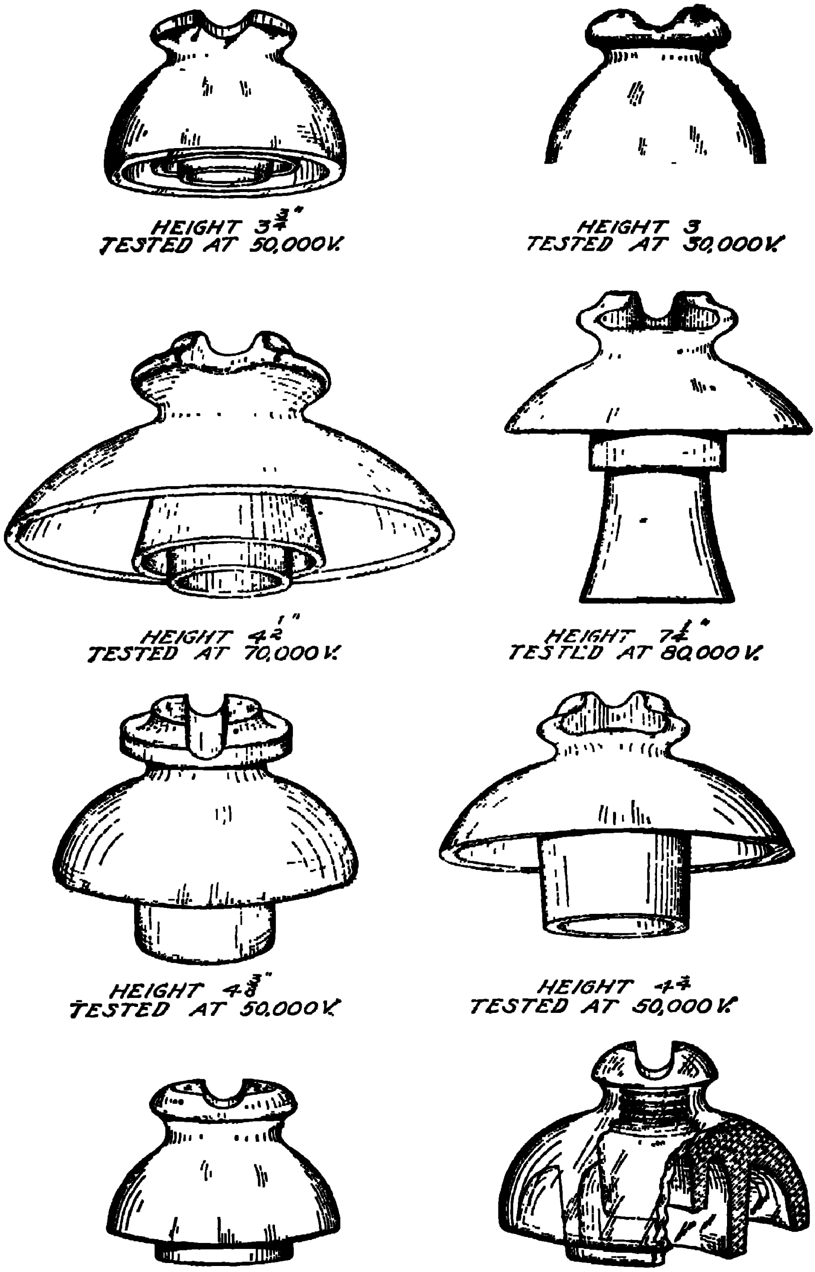


Fig. 13. Types of Pin Insulators

Pins vs. Suspension Type. At voltages up to 40,000 the insulator may be advantageously mounted on a pin, but above this voltage the pin must be of such length, to give proper clearance from the crossarms, that the structure is mechanically weak and the corners and dead ends are difficult to support in a permanent manner. For the higher voltages it is therefore necessary to resort to the use of insulators suspended from the crossarms in strings of units, which are joined by links of steel and are in tension for dead loads and lateral strains. This results in a much more substantial mechanical structure.

Pin Type. The pin-type insulator is designed in such a way as to have flash-over and puncture voltages considerably higher

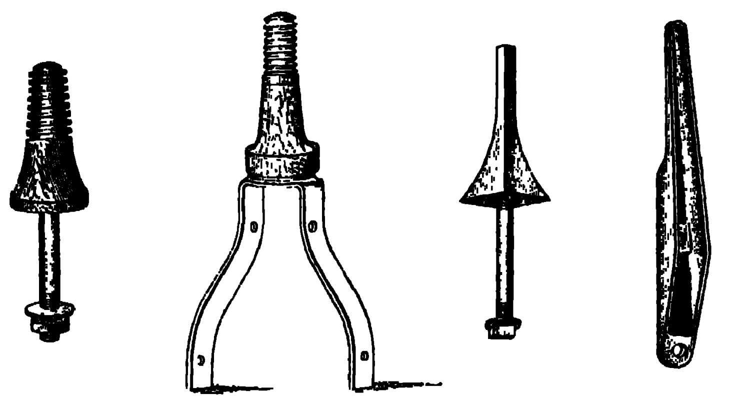


Fig 14 Types of Pins Cross-Arm 2300-6600 Volts, Pole-Top 2300-6600, Cross-Arm 10,000–33,000 Volts, Pole-Top 10,000–30,000 Volts

than the working voltage. The flash-over voltage is that required to jump from the conductor at the top to the pin at the base. The insulator must also have a series of petticoats which will keep a part of the path for leakage dry in wet weather. The various sizes of insulators shown in Fig. 13 illustrate these points.

Pin-type insulators are secured to wood pins by a screw thread in the porcelain. In the larger sizes the strength of the threads is not sufficient to carry the heavy loads placed on the insulators at times, and greater strength is secured by the use of a steel pin to which the insulator is cemented. This is most conveniently done by cementing into the insulator a steel thimble which is threaded to screw on to the steel pin. By this method

cementing is easier, and an insulator may be replaced without removing the pin.

Several types of pins which are used for transmission work are shown in Fig. 14. In some types a flange is provided to rest on the top of the arm, and in others the pin is clamped around

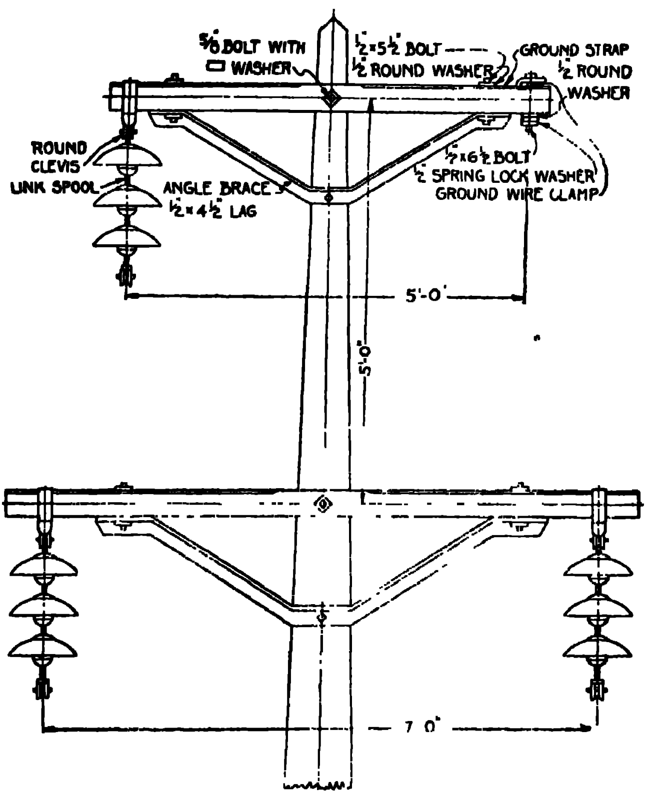


Fig 15 Arrangement of Suspension Insulators

the arm. These devices provide greater stability against side pulls and dead ends.

Suspension Type. The suspension insulator is hung in strings of three or more, allowing about 20,000 volts to each unit, the size of the unit being somewhat larger for the higher voltages. In the insulator unit, Fig. 15, the metal clamp at the bottom is fastened to the conductor, and the eye at the top fastens to the corresponding member of the clevis connector of the next unit above. The string is carried on the crossarm or tower and is

flexible to lateral stresses, so that in a wind the string may assume an angle of 30 to 45 degrees from the vertical; likewise at curves the conductor tension holds the string permanently at an angle with the vertical. The metal parts are cemented into the porcelain, and the porcelain must have sufficient thickness to prevent puncture and sufficient diameter to prevent serious flash-over at times of surge above the working voltage.

The freedom of motion of the conductor in the wind makes it necessary to provide larger clearances from the pole or tower than are required for pin-type insulators, and the crossarms must therefore be longer and the poles or towers somewhat higher.

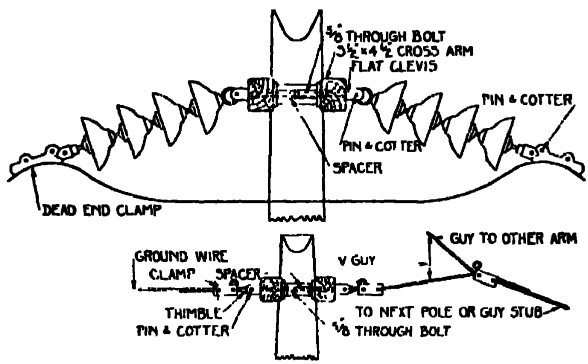


Fig. 16. Use of Strain Insulators at Corner or Dead End

At corners and dead ends it is necessary to use strings of insulators to transmit the tension of the line to the supporting structure. In Fig. 16 the horizontal strings take the tension of the span, the conductor being carried slack around the support to the next span.

The units should be connected together closely, so that when flashing over, the arc will pass from porcelain to porcelain without touching the metal connections. In this way a flash-over is not so likely to crack the porcelain and destroy the usefulness of a string of units. The flash-over voltage of a string of insulators is about half as much during rain as in dry weather. The wet flash-over voltage is from two to two and one-half times the normal voltage.

The efficiency of a string is somewhat reduced as more units are added; that is, the flash-over voltage of the string lacks more

and more of equaling the sum of the flash-over voltages of the units as the number of units is increased. This is due to the fact that the insulators have a charging current, which flows from the line conductor to the various insulators in the string. This current passes over the lower unit for all those above it, and the potential drop around the first insulator is more than for the others. If units are added, they cannot share the fall of potential equally with the others, and the efficiency is therefore lower. The rate of decline in efficiency is approximately as follows: 2 units, 93 per cent; 3 units, 88 per cent; 4 units, 80 per cent; 5 units, 76 per cent; and 6 units, 71 per cent.

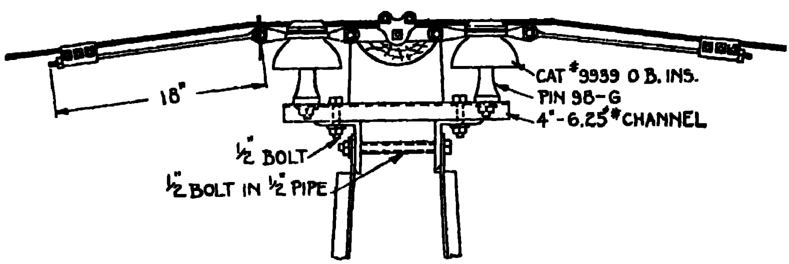


Fig. 17. Insulator Clamps for Heavy Conductors

In some cases engineers have provided arcing rings or rods around the insulator at each end to give metallic electrodes for flash-overs, thus saving the porcelain from damage. These have prevented extended interruption of service, but there is some tendency to increase the number of short interruptions caused by the tripping of a circuit-breaker when a flash-over occurs.

The connection of the conductor to the insulator must be of a rugged type in order to prevent injury by burning in case of an arc. This is especially true of a pin-type insulator where a substantial clamp around the top of the insulator is used to protect the conductor from damage, Fig. 17.

POLES

WOOD POLES

Kinds. Wood poles form the least expensive type of support for transmission lines up to about 60,000 volts for ordinary sizes of conductor. For conductors heavier than No. 0000 copper,

steel towers are often required to give adequate strength for voltages considerably lower where wind and ice loading is heavy.

Wood poles are usually of cedar or chestnut, though pine, cypress, and redwood are used to some extent in localities where they are readily available. Cedar is very widely used in the middle and northwestern states, and chestnut is used in the states adjacent to the Appalachian Range. Chestnut poles are heavier than cedar and not so uniform in their growth; the sapwood is harder and not so thick. Northern white cedar, which until recent years has been used most in the middle states, grows with a taper of about 1 inch to 5 feet of length, which gives a pole a substantial butt dimension and therefore ample strength at the ground line. The large butt dimension also contributes to the life of the pole, as the most rapid decay takes place at the ground line. The larger sizes of Northern cedar poles have a life of 20 to 25 years in many localities. Western cedar, which grows in Oregon and Idaho, has a taper of 1 inch to about 9 feet of length. The butt diameter is therefore several inches less than that of a Northern cedar pole with the same top diameter, and it is necessary to use larger top diameters than with Northern cedar to secure the same degree of strength. The fiber strength of Western cedar is higher than that of Northern cedar, however, so that it is not necessary to have equal cross-section for equal strength.

Strength of Wood Poles. The fiber stress per square inch in a round timber such as a pole is

$$S=\frac{12\times 32}{3.14}\cdot\frac{PL}{d^3}=\frac{122.2\ PL}{d^3}$$

where P is the force acting on the pole at right angles at the equivalent height L above ground in feet, and d is the diameter at the ground line in inches. For an assumed value of S and a computed value of P the size of the pole required is known from

$$d^3=\frac{122.2\ PL}{S}$$

However, in a pole having a circular cross-section the weakest point is that at which the diameter is 1.5 times the diameter at the point where the load is attached. For Northern cedar and

chestnut this is often at a point several feet above the ground line. In a Northern cedar, having a taper of 1 inch in 5 feet, if the load is applied at a point where the diameter is 8 inches, the point of maximum stress will be at a diameter of 12 inches. This will be $(12-8)\times 5$, or 20 feet, below the point of attachment of load, which would be above the ground line for loads due to line wires. With a Western cedar, having a taper of 1 inch in 9 feet, the point of maximum stress would be $(12-8)\times 9$, or 36 feet, below the point of attachment. In most cases this would be at or below the ground line. When the point of greatest stress is above the ground line, the equation for finding the diameter d_2 at that point is

$$d_2=\frac{18.11\ PL}{d_1^2S}+d_1 \text{ in.}$$

in which d_1 is the diameter at the point of attachment of the load. The value of S varies somewhat in the different kinds of wood and with the factor of safety which is considered permissible. The ultimate fiber strength of Northern cedar averages about 3600 pounds per square inch; that of Western cedar and chestnut average about 5100 pounds.

In calculating loads caused by curves and self-supported corners or dead ends, where the stress is continuous, the fiber stress should be kept low enough to prevent excessive distortion. This usually makes it necessary to use a working stress of about 15 to 20 per cent of the breaking strength. For conditions such as ice and wind loading, which are transient, the working stress under the assumed load condition may be 40 to 50 per cent of the ultimate strength. These figures allow for some variations in quality and for partial loss of cross-section by decay.

Dead-End and Corner Loading. At dead ends which are not guyed the entire tension of the line wires must be carried by the pole, and at corners the resultant load of the two adjacent spans must be so carried.

Assuming that a Northern cedar pole is to sustain the tension of three No. 0 bare wires amounting to 200 pounds each, one wire being attached 28 feet above ground and the other two wires at 25 feet, that the maximum working fiber stress S is to be 600 pounds per square inch and that the diameter is 9 inches

at the average height of attachment, the size of the pole at the point of maximum stress will be

$$d_2=\frac{18.11\ PL}{d_1^2\times S}+d_1 \text{ in.}$$

PL equals: 200×28, or 5600 foot pounds for 1 wire; and $2\times200\times25$, or 10,000 foot pounds for 2 wires; which gives a total of 15,600 foot pounds for 3 wires. Therefore

$$d_2=\frac{18.11\times15600}{9^2\times600}+9=5.8+9=14.8 \text{ in.}$$

This would be at a point 5.8×5, or 29 feet below the point of attachment, which is 1 foot below the surface of the ground since the highest wire is only 28 feet above the surface.

In the case of a corner with these same wires turning at right angles, the moment PL on the pole would be $\sqrt{15600^2+15600^2}$, or 22,000 foot pounds.

$$d_2=\frac{18.11\times22000}{9^2\times600}+9=8.2+9=17.2 \text{ in.}$$

This would be at a point 8.2×5, or 41 feet below the point of attachment, which is below the end of the pole. Applying the rule for cases where the point of maximum stress is below the surface, the diameter at the surface must be

$$d^3=\frac{122.2\ PL}{S}=\frac{122.2\times22000}{600}=4470$$

$$d=\sqrt[3]{4470}=16.45 \text{ in.}$$

With this diameter at the ground line, the diameter at the point of attachment must be $16.45-\frac{26}{5}$, or 11.25 inches, the equivalent average height of attachment being $\frac{15600}{600}$, or 26 feet.

If this were a Western cedar pole with a taper of 1 inch in 9 feet and a fiber strength of 800 pounds, the diameter at the surface would be

$$d^3=\frac{122.2\times22000}{800}=3350$$

$$d=\sqrt[3]{3350}=15 \text{ in.}$$

With a diameter of 15 inches at the ground line, the diameter at the point of attachment must be $15-\frac{26}{9}$, or 12.1 inches.

Transverse Loading. Where a line changes direction at an angle of less than 90 degrees, the conditions are often such that guys cannot be used and stresses must be computed to determine pole sizes. In such cases a simple method of determining the transverse pull is that shown in Fig. 18. Measure off 100 feet along each span adjacent to the pole and by sighting from *a* to *b* locate the point *c* opposite the pole, then measure the distance *g* from *c* to the pole. The force acting on the pole is

$$P=\frac{2gT}{100}$$

in which T is the sum of the tensions of all the wires.

With three No. 0 wires having a tension of 200 pounds each and a value of 20 for g the force on the pole is

$$P=\frac{2\times20\times600}{100}=240 \text{ lb.}$$

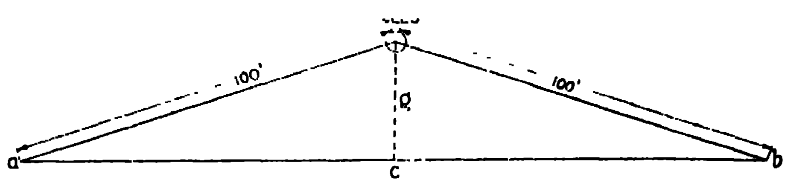


Fig. 18 Transverse Stress at Turn in Line

If attached at an average height of 26 feet, the moment PL equals 6240 foot pounds.

The action of the wind on ice-laden conductors may subject poles to transverse stresses of considerable magnitude. Assume a pole line carrying six No. 0 bare wires on which there is a coating of ice having a radial thickness of ½ inch. The span lengths at each side of a pole are 150 and 170 feet respectively, and there is a wind pressure of 6 pounds per square foot of projected area at right angles to the line.

From Table IX the diameter of No. 0 is 0.325 inch. Adding the ice, this becomes 0.5+0.5+0.325=1.325 inch. In 100 feet the projected area per wire is $\frac{100\times1.325\times12}{144}$, or 11 square feet. The

length of wire carried by the pole being $\frac{150+170}{2}$, or 160 feet, the area per wire is 1.6×11, or 17.6 square feet, and the total for 6 wires is 6×17.6, or 105.6 square feet. The force of the wind being 6 pounds per square foot, the stress on the pole is 6×105.6, or 633.6 pounds. Assuming this to be applied at an average height of 30 feet above ground, the moment would be

$$PL = 30 \times 633.6, \text{ or } 19008 \text{ ft. lb.}$$

Ice and wind loading being a transient condition and the two rarely occurring simultaneously, it is reasonable to permit the fiber stress to go higher than is desirable where the stress is continuously applied. Hence a value of 1400 for S in Northern cedar or 2000 in Western cedar or chestnut may be assumed. With Northern cedar having a 7-inch diameter at 30 feet above ground

$$d_2 = \frac{18.11 \times 19008}{7^2 \times 1400} + 7 = 5 + 7 = 12 \text{ in.}$$

The point of greatest fiber stress is 5×5, or 25 feet below the point of attachment, or about 5 feet above ground. Hence a pole with a diameter of 7 inches at 30 feet above ground would be ample to withstand the loading due to the action of the wind on the wires.

The moment of a 40-foot pole set with 34 feet of its length above ground with a 7-inch diameter at 30 feet and a 13-inch diameter at the surface is

$$PL = \frac{H^2 F (d + 2d_1)}{72}$$

in which H is the height above the surface of the earth in feet and F is the pressure of the wind in pounds per square foot

$$PL = \frac{34^2 \times 6 \, [13 + (2 \times 7)]}{72} = 2601 \text{ ft. lb.}$$

Adding this moment to the moment of the ice-laden wires, the total moment is $19008 + 2601$, or 21609 foot pounds. For the total

$$d_2 = \frac{18.11 \times 21609}{7^2 \times 1400} + 7 = 5.7 + 7 = 12.7 \text{ in.}$$

The point of greatest fiber stress would be 5.7×5, or 28.5 feet below the point of support, or 1.5 feet above the ground line. A pole with a 7-inch diameter at 30 feet above ground and a 13-inch butt at ground line will therefore carry the load safely.

Example. **What should be the butt diameter of a 40-ft. Western cedar pole with a 7-in. top which carries six No. 00 bare wires laden with ½ inch of ice radial thickness, with a wind pressure of 6 pounds acting at right angles to the line, if the line is straight and the length of span each side of the pole averages 120 feet; if the line makes a turn of 15 feet in 120 feet and the wires have a tension of 250 pounds each?**

Ans. **Straight line 10.8 inches; at turn 11.9 inches**

STEEL POLES AND TOWERS

Range of Use. Where lines must be carried across railroads or at other high levels and where the size of the conductor, the character of the service, the voltage, and the permanence of the

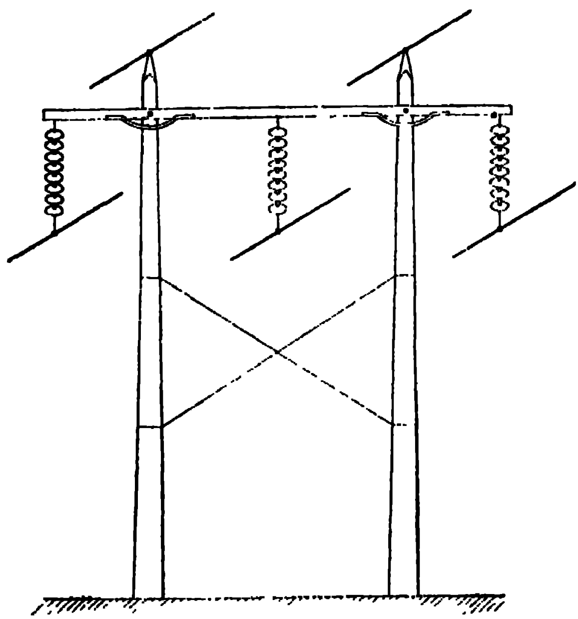


Fig. 19 Use of Double-Pole Line

enterprise demand a high degree of reliability and durability, the conductors are carried on substantial steel structures designed to have greater strength than a wood pole or combination of poles.

However, the increased cost of steel structures is sometimes not justified by the conditions, and the problem of increased spacings for two circuits at high voltages is sometimes met by the use of a double line of wood poles set about 15 feet apart, with crossarms between them. The structure is so arranged as to be

materially stronger than two separate pole lines would be, and is considerably less expensive than steel construction. This type of construction is shown in Fig. 19.

Steel construction is often used for special cases in a wood-pole line, such as a long span across railroad tracks or other obstacles where unusual height is necessary for clearance. Such poles are usually of lattice-work construction since the space for

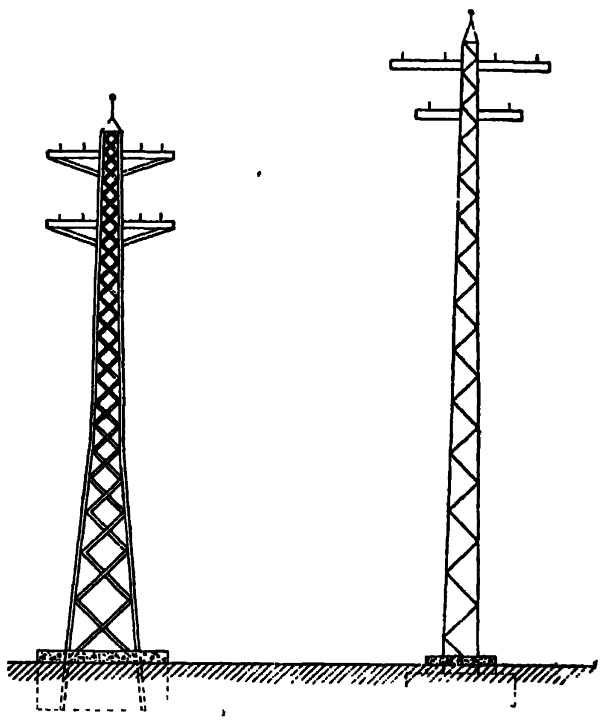


Fig. 20 Types of Lattice Poles

foundations is limited and a broad based structure is not possible. For river crossings, where space on the banks is ample, a tower construction is more common, the spread of the base being 10–20 feet or more according to the height required and the span length.

With lines on a private right of way there is usually ample room for broad-based towers. In agricultural districts objection is sometimes made to the use of large bases, if they stand in ground used for cropping. With a smaller base the steel work

must be heavier and more closely latticed than with broad-based towers.

A few typical examples of narrow- and medium-based structures are shown in Fig. 20, and several types of broad-based towers in Fig. 21.

Span Lengths. The difference between the cost of steel structures and that of wood poles is lessened materially by the possibility of using much longer spans, thus requiring a much smaller number of towers and foundations per mile than poles.

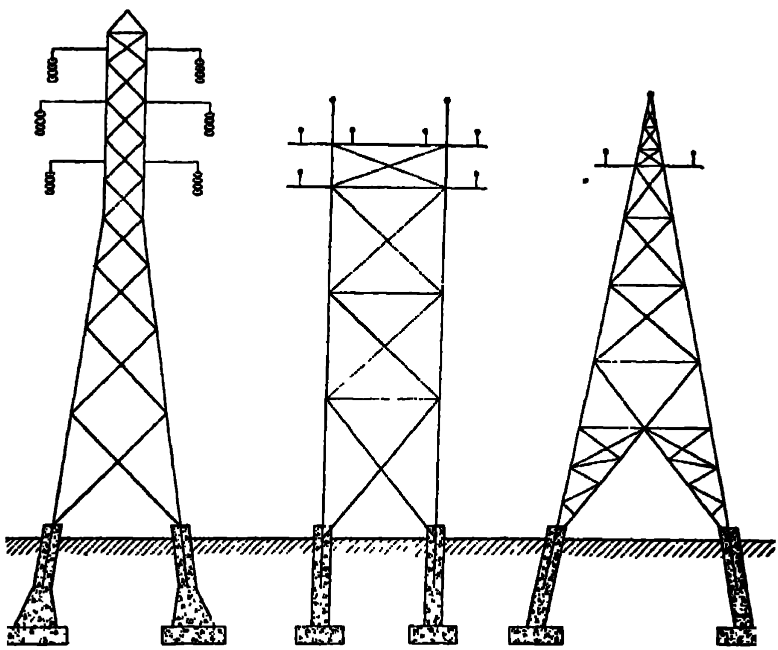


Fig 21. Types of Towers

This also reduces the number of insulators in the same proportion and tends to reduce interruptions of service from insulator failures. On the other hand, as the spans become longer, the sag and the tension of conductors increase and additional height must be added to give the required clearance at the low point of the span. Since this, in turn, requires a heavier construction and foundation and as the cost of foundations is a considerable part of the cost of steel structures, there is an increase in cost for span lengths of 800 to 1000 feet as compared with spans of 500 to 600 feet.

This refers to lines having conductors of No. 0 or larger. The length of spans is also restricted at lower voltages by the tendency of wires in long spans to come into contact and burn off as there may not be sufficient separation between conductors.

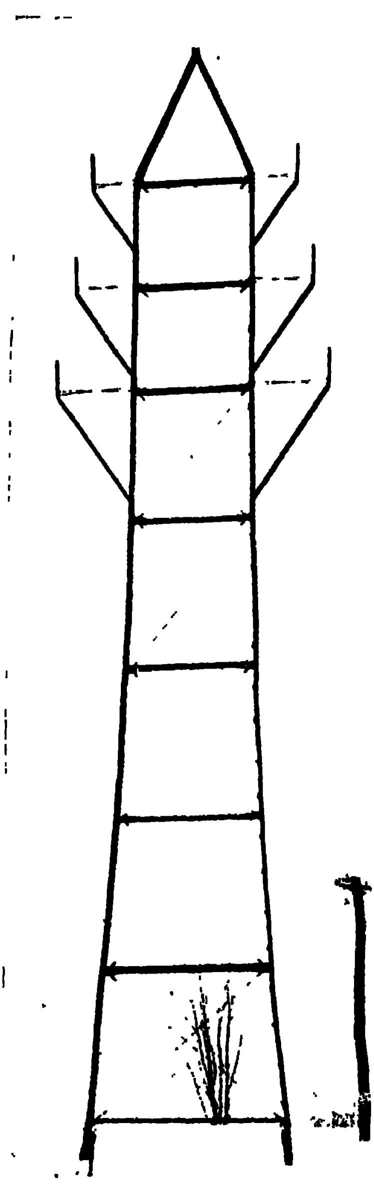


Fig. 22. Flexible Type of Steel Structure

Spans of 300 to 600 feet are most commonly used in country where the foundation sites can be selected without difficulty. In a mountainous region spans often run to 1000 feet or more, since the towers must be on the high points and there are no obstacles to prevent the use of ample sags and separations.

Flexible Structures. In straight runs transverse strength is secured at less expense by the use of a structure which is not braced against forces acting in the direction of the line. This type of structure, Fig. 22, is made of somewhat heavier members but requires only one-half as much foundation as a tower having four feet. The two-footed structure can move somewhat, as may be necessary to readjust the tensions in adjoining spans, and is known as a *flexible tower*.

The flexible structure offers comparatively small strength against the stresses arising in case all or part of the wires of the line are broken. It is therefore necessary to put in self-supporting towers at intervals to check the spread of trouble in such an emergency.

Such structures are, of course, also necessary at points where the line makes an abrupt turn.

On lines having the smaller sizes of conductors the use of self-supporting towers may be reduced in straight runs by the use of head guys at suitable intervals, these guys being connected each way from the top of one tower to the base of the one adjoining or, if spans are long, to an anchor provided for the purpose.

Self-Supporting Structures. The self-supporting type of tower includes towers showing a considerable range of strength and design of supporting members. This range extends from the tower which is made adequate for the transverse stresses and a part of the longitudinal stresses to the tower which must support the entire unbalanced forces of a long river crossing at a height much above that of the rest of the line.

In case rigid towers are used throughout the line, it is usually not necessary to provide strength sufficient to care for the breaking of all the wires of the line. No more than two are likely to break at any one point in the line.

With suspension-type insulators, when a line breaks, the strings swing each way with the tension of the line, thus considerably relieving the stress due to the unbalanced load. This further reduces the necessity of providing strength to hold the full tension of all the wires.

The maximum stresses are those occurring in connection with ice loading of conductors at the time of a break, these stresses usually being greater than the transverse stresses due to ice and wind loading. With crossing and other dead-end towers the strength must be ample to take care of the ice and wind loading, and if the spans are over 300 feet, such structures must be made of quite heavy materials.

Specifications for Towers. The detailed calculation of tower members is a matter for structural designers and must be left to the manufacturer who should assume responsibility for the complete design. The transmission engineer must, however, give the manufacturer the specifications to be met by the structure, which must include: the maximum allowable spread of the base; the height required for conductor clearance from other structures and the ground; the size of conductor; the length of span; the condi-

tions of maximum loading; the number of circuits to be carried; the voltage and phase of the line; the type of insulator to be used; and the type of structure, whether flexible, rigid line, or dead end. The specifications should provide that all members be well galvanized, including bolts and nuts used for assembly in the field. The details of connections to insulator strings or pins and the connections to foundations must be given, and in case of towers which are not to stand on level foundations, the necessary data as to the profile of the surface.

Foundations. The character of foundations for steel structures varies according to the spread of the base and the height of the structure. Narrow-base poles (that is, less than 4 feet) are usually set in a solid block of concrete about 6 feet deep and flared out at the bottom to give the necessary stability. For towers having broader bases separate footings are provided for each leg, with rods to which the superstructure is bolted set in the concrete.

Dead-end and crossing towers often have so large an overturning moment that the concrete block must be quite massive. In such cases the foundation, therefore, takes the form of two concrete blocks, one taking the compressive stress on the crossing side and the other the lifting stress on the other side of the tower.

The overturning moment is PL feet pounds, P being the tension of the wires of the span and L being the equivalent height of the points of attachment. Thus for a tower carrying 6 wires having a tension of 2500 pounds each at an equivalent height of 50 feet, the moment is $6 \times 2500 \times 50$, or 750,000 foot pounds. If the base has a spread of 20 feet between footings in the direction of the stress, the force acting on the footings is $\frac{750000}{20}$, or 37500 pounds. This must be met by the combined weight of concrete and earth on the far side and by a sufficient area of bearing surface on the footings of the span side to prevent the earth from settling under the compressive force. The area of bearing surface depends, to a large extent, on the character of the soil, clay and rock requiring less surface than sand and swampy ground. It is quite important that the bearing surface provided be ample as

the supporting power of the soil cannot always be determined accurately.

MISCELLANEOUS LINE PROBLEMS

PROTECTIVE EQUIPMENT

Lightning Arresters. Overhead lines are very generally subject to the influence of lightning discharges. This influence is felt in the tendency of the electrical charge to jump around or to

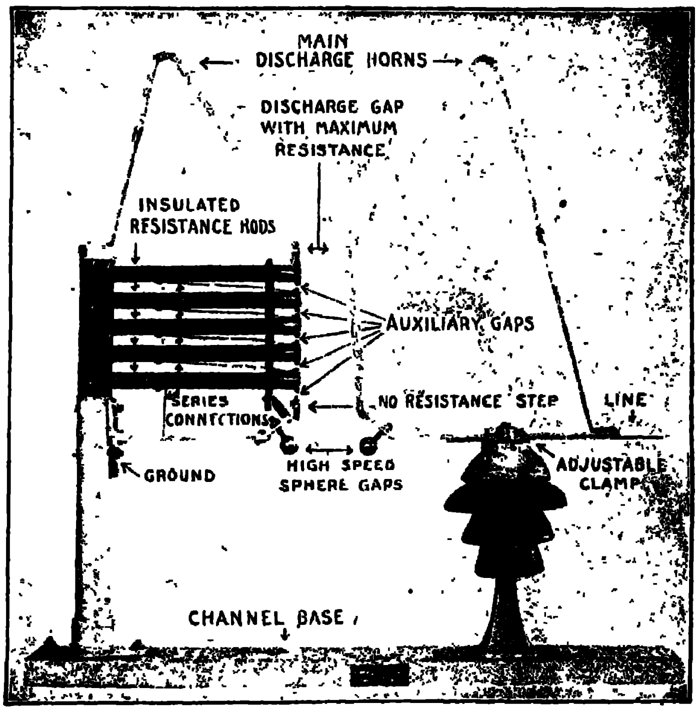


Fig. 23. Horn Gap Arrester with Resistance

puncture insulators and to break down the insulation of transformers and other apparatus. The damage is such that provision must be made to prevent it as far as it is practicable to do so.

Spark-Gap Type. The protection of substation equipment requires that the discharge gaps be so arranged that the high-potential charge may pass to ground without puncturing the insulation or otherwise damaging the apparatus. The devices designed for this purpose are known as lightning arresters, since the most

severe discharges take place in connection with lightning storms. The lightning arrester embodies spark gaps, choke coils, and in some cases, resistance for limiting the flow of power current following the discharge. The spark gaps are set to discharge at a pressure sufficiently above the line voltage to prevent unnecessary discharges, and yet not so high as to allow insulation to be injured. Choke coils are provided between the apparatus and the

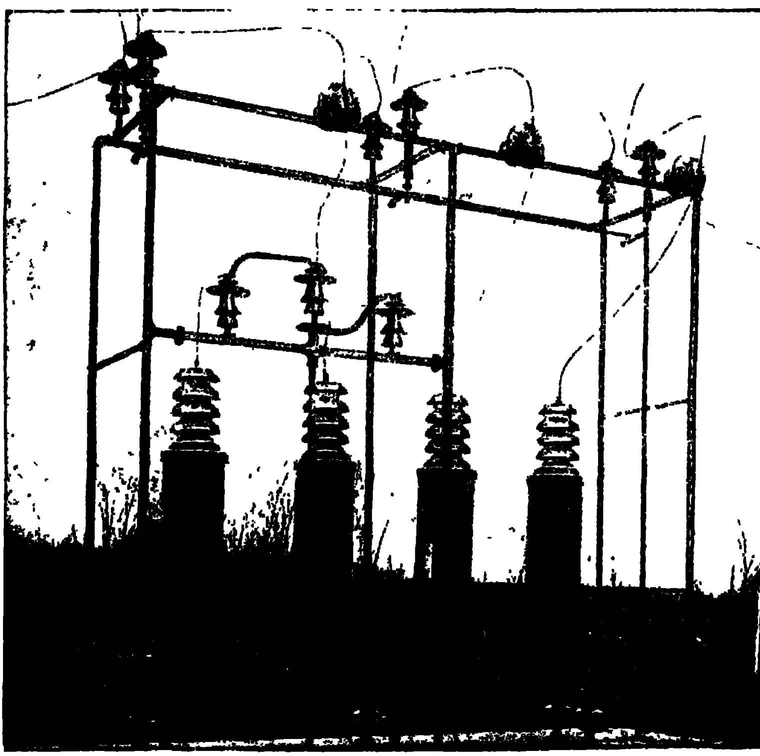


Fig. 24. Outdoor Type 60,000-Volt Aluminum Lightning Arrester.

discharge gaps so that high-frequency discharges such as are set up by lightning will be choked back and sent across the gaps instead of entering the windings.

For the less important substations the lightning-arrester equipment must be inexpensive and usually is best placed out of doors. For such situations it is often combined with the pole-top switching facilities in some form similar to that shown in Fig. 23. The discharge gaps are provided with flaring rods along which

the power arc rises until it is attenuated to the breaking point. If suitable resistance is provided the line will not be opened by the ordinary discharge, and no damage is done to the equipment.

Electrolytic Type. Large substations usually justify the best form of protection which can be provided, and this is found in the electrolytic form of lightning arrester. This arrester, Fig. 24, consists of a stack of cones of aluminum in a tank of electrolyte, the number being fixed by the voltage of the line, with a resistance in the ground connection. The tanks are connected from each phase to a neutral point. If the neutral of the system is grounded, the arrester neutral is carried to ground through the resistance, but if not, another tank is interposed between the arrester neutral and ground, thus making four tanks in all. The electrolyte is covered with a layer of oil to retard evaporation. The tanks are not connected directly to the line but have an air gap in the circuit to prevent a continuous flow of energy, which would cause heating. The principle on which the arrester acts is that the aluminum oxide permits current to flow in only one direction. Hence the lightning discharge can pass to ground but the flow of power current is quickly stopped. However, in order to insure the film of oxide being always ready for service, the arrester must be charged by closing the air gap for a few seconds each day, thus renewing the film. This requirement, with the higher first cost, makes it necessary to limit the use of the device to situations where an operator may visit the installation daily and where the value of the substation equipment and the importance of the service are great.

The electrolytic arrester has a higher discharge capacity than the spark-gap type, and hence can take care of a wider range of high-potential discharges. However, cases have been known where strokes in the immediate vicinity have placed so severe a duty upon the arrester that the cones have been burned through and their usefulness destroyed. But it is not to be expected that any equipment will be able to withstand the force of a direct stroke in the immediate vicinity of the substation, and fortunately such strokes are not of frequent occurrence.

Oxide Film Arrester. The fact that the electrolytic type of lightning arrester requires charging daily and is subject to freezing

at lower temperatures led to the development of an arrester known as the oxide film arrester, Fig. 25, in which the general principle of action is the same but the electrolytic medium is not a liquid but a gelatinous material built up in discs with the required number in series for the voltage of the line. The use of a non-liquid material obviates the necessity for daily charging since the film of aluminum oxide is not dissolved by the electrolyte as it is in the electrolytic arrester. The use of oil is also unnecessary, reducing the fire hazard in case of a direct stroke. A single disc is shown in Fig. 25, while Fig. 26 shows the method of securing greater resistance by increasing the number of discs through which the discharge must pass. An outdoor type of arrester is shown in Fig. 27.

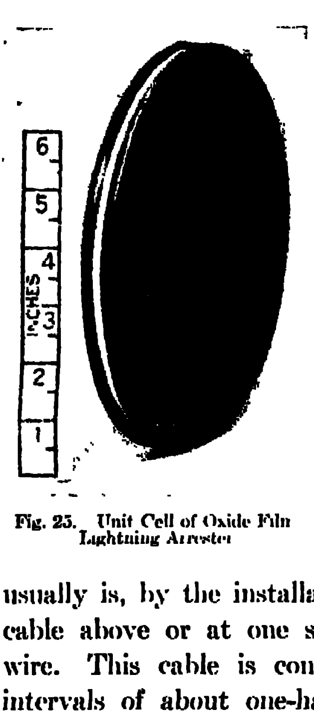


Fig. 25. Unit Cell of Oxide Film Lightning Arrester

The oxide film arrester has not been through a sufficient number of years of service to bring it to a final stage of development, but the service records thus far indicate that it will probably supplant the electrolytic type of arrester in the course of time.

Ground Wires. It is not feasible to protect insulators by lightning arresters, since the arrester is more likely to be a cause of trouble than the insulator, but the line can be protected, and usually is, by the installation of a galvanized or copper-clad steel cable above or at one side of the line conductors as a ground wire. This cable is connected solidly to ground connection at intervals of about one-half mile, thus making a sort of ground shield which tends to limit the accumulation of high-potential charges upon the line conductor.

On pole lines it is often carried on a "bayonet" attached at the top of the pole, thus placing it symmetrically with reference to the line conductors. This serves for two circuits as well as one. On steel structures it is carried above the line, also, but where suspension insulators are used in a vertical arrangement the spacings are such that it is usually considered necessary to

have a separate ground conductor above each circuit on two circuit lines. Copper-clad steel is used where greater permanence is desired, its life being longer than that of galvanized cable.

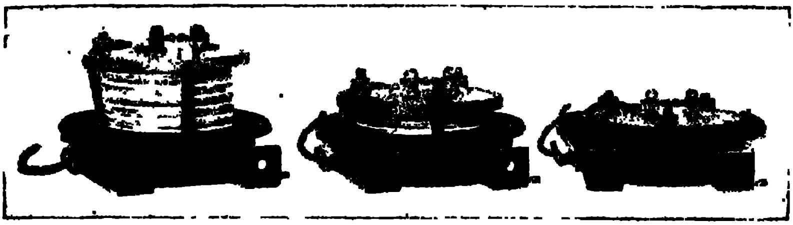


Fig. 26 Types of Oxide Film Lightning Arresters with Covers Removed. Ratings 325-650, 900-1350, and 2100-2600 Volts. For Alternating or Direct Current

Discharge Points. For the protection of suspension insulators from injury at the time of a flash-over it is usual to provide metal points or rings projecting from the unit at each end of a

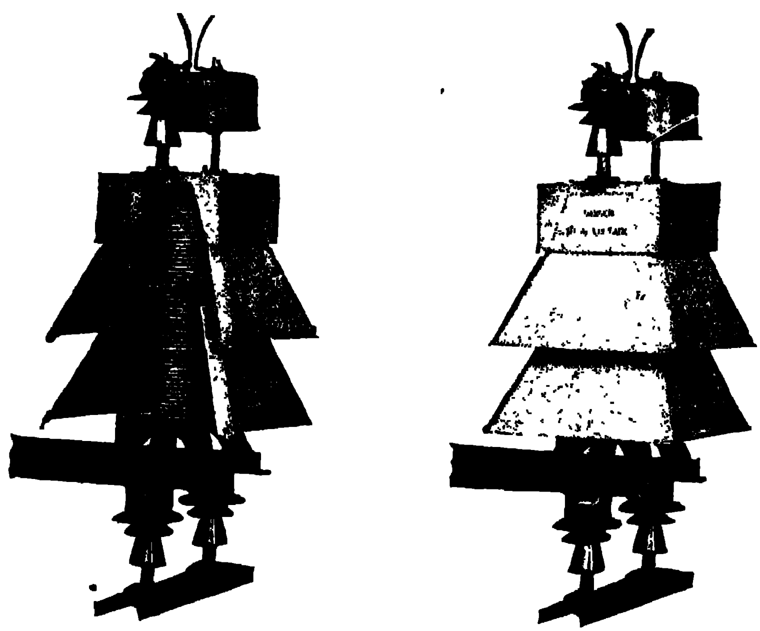


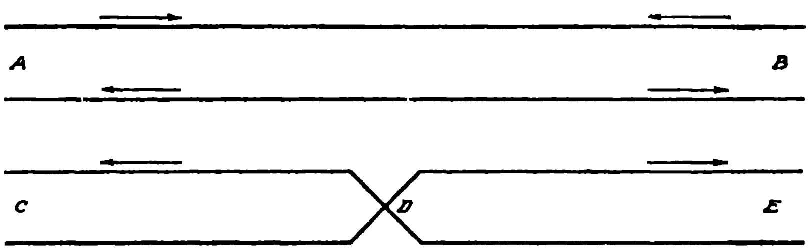
Fig. 27. Phase Section of 15,000-25,000-Volt Outdoor Lightning Arrester with Side of Housing Removed

string, so that the arc will be formed between metal terminals and will not form on the edge of porcelain petticoats and break them. This is also done to some extent on the larger sizes of pin-type insulators and is effective in reducing the number of

insulator failures. The principal objection to this plan is that when a discharge occurs it usually draws enough current to open the circuit breaker, thus causing a short interruption of service. These are likely to be more frequent where discharge points are used than where they are not, but, on the other hand, a broken insulator may cause a much more extended interruption.

TRANSPOSITIONS

General Problems. Where transmission lines are parallel to other lines for some distance it is often found desirable that they be transposed. A three-phase line is transposed by interchanging



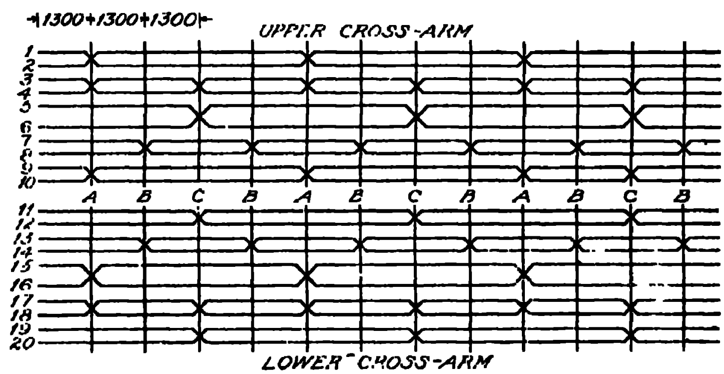


Fig. 28. Transposition Diagram of Ten Two-Wire Circuits to Reduce Mutual Inductance

the position of two of the wires in such a way as to make one-third of a spiral of the line. Two repetitions at suitable intervals make a complete spiral, and if the sections are of the proper length, the electrostatic and magnetic unbalance resulting from unequal separation of the phases when not transposed may be neutralized.

If there are only power lines involved, the effect on the operation of the lines is not great in most cases, an unbalanced charging current and pressure sometimes being observed.

Concerning Telephone Lines. Where telephone lines are concerned the inductive effects are very marked and must be neutralized by a careful system of transpositions. The transpositions in the telephone line are usually sufficient without putting extra transpositions into the power line, but where there are transpositions in the power line, the arrangement and location of the transpositions in the telephone line should be co-ordinated with those in the power line, in somewhat the manner shown in Fig. 28. This represents the transposition effected in ten two-wire circuits carried on two crossarms below or at one side of the power line.

Where the telephone lines include phantom circuits, as is now common in long-distance lines, the transpositions become very complex and the co-ordination of the transpositions of the power and telephone systems is indispensable to satisfactory operation of the telephone system.

Steel-Tower Lines. The problem of transposing steel-tower lines without producing unsafe clearances is such that special towers are often necessary at transposition points. This involves great expense if the necessity of introducing the transposition tower arises after the line is built, and in such cases it is important that all available means of transposing the telephone lines be tried before resorting to transposition of the power line.

LINE CROSSINGS

Safety of Lines. The points at which transmission lines cross other lines of overhead wires are considered hazardous when the lines crossed are used for communication purposes. This is due primarily to the fact that telephone, telegraph, and train-dispatching circuits employ low voltages and are not insulated sufficiently to prevent breakdown when subjected to transmission voltages. Protective fuses are used to guard against crosses with voltages below 7500, but such protection is not practical at higher voltages. It is therefore customary for telephone and railroad companies to specify in detail the character of transmission-line

construction which shall be used in making crossings over their lines.

National Electrical Safety Code. This matter was the subject of extended study and discussion for some years on the part of the power and communication engineers (whose interests are conflicting) until the U. S. Bureau of Standards took up a study of the safety of lines. With the co-operation of engineers representing all the interests involved the National Electrical Safety Code was drafted and issued for trial and constructive criticism and is rapidly taking the place of other specifications drafted by the various railroads and communication companies.

The general principles upon which these rules are based are as follows:

The power line, being of larger conductors and generally the stronger, shall be carried above the communication circuits.

The power-line construction shall be made strong enough to stand up under the worst conditions of weather which are likely to be experienced.

The clearances above the communication lines shall be such that they cannot become crossed when loaded with sleet.

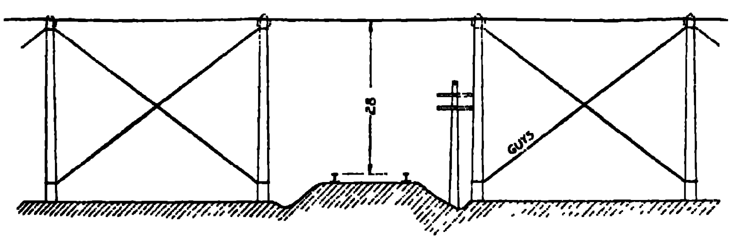


Fig. 29. Construction at Crossing over Other Lines

Some of the principal requirements for lines of over 7500 volts at crossings are as follows:

The strength of the conductors and their supports must be such that when loaded with ice $\frac{1}{2}$ inch in radial thickness and subject to a wind pressure of 12 pounds per square foot at a temperature of 0° F., the conductor material shall not be stressed to more than 50 per cent of its ultimate breaking stress.

The poles and towers must also have sufficient strength to withstand a 12-pound wind pressure with the conductors loaded with $\frac{1}{2}$-inch ice. The poles, towers, and pins must be strong enough to withstand the unbalanced tension of the line in case all the wires in the span are broken.

Head guys must be used at each side of the crossing, Fig. 29, and with heavy conductors or long spans it is usually necessary to use strain insulators of the suspension type instead of pin insulators. Where side guys cannot be used, the poles or towers must usually be of the self-supported type.

TABLE X*

Sag at 60° F. for Medium- and Hard-Drawn Bare Copper Wires

Size A W G	Grades of Construction	Span Lengths (feet)										
		100	125	150	175	200	250	300	400	500	700	1000
		Sag (inches)										
HEAVY-LOADING DISTRICTS												
8	C	12	18	27								
6	A	12	18	27								
	B	10	15	22								
	C	10	15	22	33							
4	All	10	15	21	28	38	71	115				
2	All	10	15	18	21	24	41	68	138	228		
1	All	10	15	18	21	24	40	59	120	204		
00	All	10	15	18	21	24	36	50	102	168		
0000	All	10	15	18	21	24	32	42	84	132		
MEDIUM LOADING DISTRICTS												
8	C	8	12	18								
6	All	8	12	18	24							
4	All	8	12	18	24	32	42	69	111			
2	All	8	12	18	22	26	36	50	88	150	324	
1	All	8	12	18	21	24	31	40	72	124	286	
00	All	8	12	18	20	22	27	33	55	92	192	415
0000	All	8	12	18	19	21	24	27	48	76	154	323
LIGHT-LOADING DISTRICTS												
8	C	6	9	13	20							
6	All	6	9	13	18	21						
4	All	6	9	13	18	22	25	40	80	137		
2	All	6	9	13	18	18	20	30	59	98	208	
1	All	6	9	13	18	18	20	28	52	85	178	380
00	All	6	9	13	18	18	20	26	46	72	140	290
0000	All	6	9	13	18	18	20	21	43	66	126	246

All construction over communication wires must be of the highest grade, called Grade A, and the same must be used for heavy loading (except in states bordering the Gulf of Mexico and the Pacific Ocean where sleet does not occur). Heavy loading assumes ½ inch of ice and an 8-pound wind pressure at 0° F. for wire tensions and a 12-pound wind for transverse stresses on poles and towers.

The sag at 60° F. must not be less than the values given in Table X, these values being based on a tension at heavy loading which will not exceed 50 per cent of the breaking strength of the conductor. These limits are such that No 4 soft copper, or No. 8 hard copper, or No. 1 aluminum is the smallest size which can be used for conductors in a crossing.

* The values in Table X should not be greatly exceeded as there would be danger of wires becoming crossed through excessive slackness at higher temperatures

Crossarms and pins must have a strength sufficient to withstand the unbalanced pull to a maximum of 700 pounds. If the tension is greater than this, the arms must be doubled and strain insulators used instead of pin-type insulators.

Poles must not have a stress of over 50 per cent of the breaking strength of the fiber when subjected to the assumed heavy loading conditions. They must be replaced when their strength has been depreciated by decay to two-thirds of initial strength.

Clearances must be maintained as follows:

From Wires at	To Communication Circuits	To Guys, Messengers, etc.	To Other Electric Lines
750–7500 volts	4 feet	2 feet	4 feet
7500–50000 volts	6 inches	4 inches	6 inches
Over 50000 volts	Add ½ inch per 1000 volts above 50000		

With suspension insulators sufficient space must be added so that if the wire in an adjoining span should break, the clearances in the crossing span would not be reduced below 75 per cent of normal amounts.

The clearance between wires of opposite polarities in the same circuit shall be 12 inches plus 0.2 inch for each 1000 volts above 7500; from conductors to guys or wires run vertically on the same pole, 6 inches plus 0.2 inch for each 1000 volts above 7500; and from conductors to poles, towers, or crossarms, 3 inches plus 0.2 inch for each 1000 volts above 7500.

In the case of conductors carried on suspension insulators in such a way as not to prevent lateral movement under transverse stresses, the clearances from the conductors to the tower, pole, or other conductors must be increased by ½ the length of the suspension insulator string.

In railroad crossings the clearance above the rail must be 28 feet for circuits under 15,000 volts, 30 feet for circuits of 15,000 to 50,000 volts, and an additional ½ inch per 1000 volts above 50,000 volts.

SECTIONALIZING SWITCHES

Locating Trouble. Branch lines and lines which are arranged so that they can act as a reserve for each other are commonly provided with means for disconnecting and connecting at junction points to facilitate the resumption of service on the portions of the system which are not in trouble. In case of taps the switch is useful in testing to locate trouble and in resuming service after the trouble has been located and repaired. At junctions the arrangement of switches should be such as to permit ready determination of the tap on which the trouble is located. These conditions may be readily met by the use of knife switches mounted on insulators suitable for the voltage and operated by a handle from a point below the wires. There is rarely any occasion to open these switches while they are carrying load, and an air-break is therefore sufficient. Where there may be occasionally a

small current, such as the exciting current of transformers, to be broken, the switches are equipped with horn gaps to break the arc and save burning the contacts. The switches used for this class of service are illustrated in Fig. 30.

Some of the ways by which interconnected transmission systems may be equipped to facilitate operation and rapid resumption of service are shown in Fig. 31. In the case of trouble while substation 3 was being carried on the east line, the patrolman would

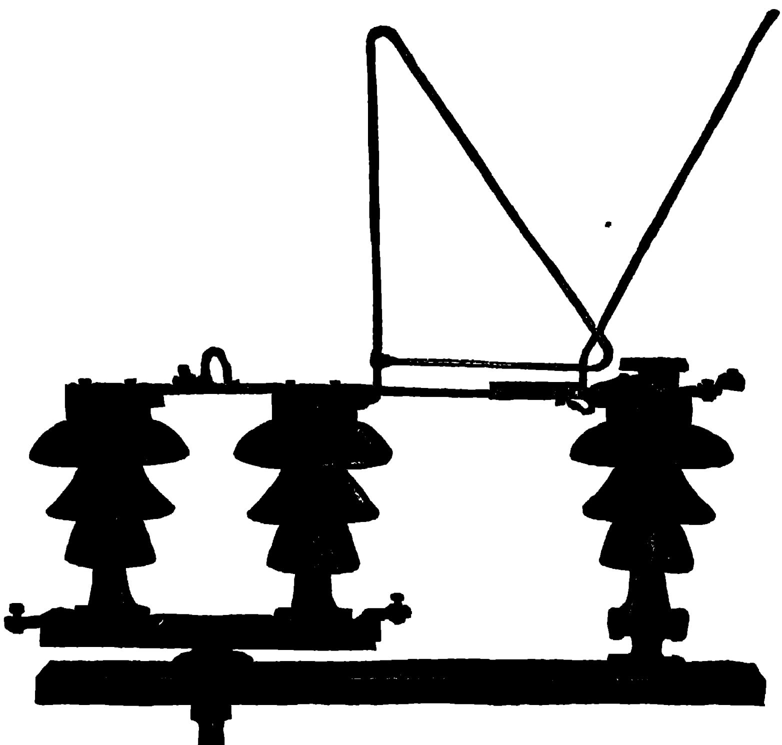


Fig. 30 Pole-Top Switch

be sent to the junction on the east line and instructed to open the switch in the main line. When this was reported done, the operator would have the main line made alive. If the trouble was still on, he would know it must be at some point *A* on the main line between the junction and the station. He would then arrange to have a man proceed to the junction on the west line with instructions to close the switch on the tap going east, which would make alive substations *3*, *4*, and *5*, putting all the load on

the west line. If this was known to be too much for the west line, the switch to *3* or *4* might first be opened, leaving part of the load off until the east line could be repaired. In a similar way trouble at any other point on the system could be handled.

If the substation is a small one and does not justify the expense, a single switch is installed by which it can be cut off in

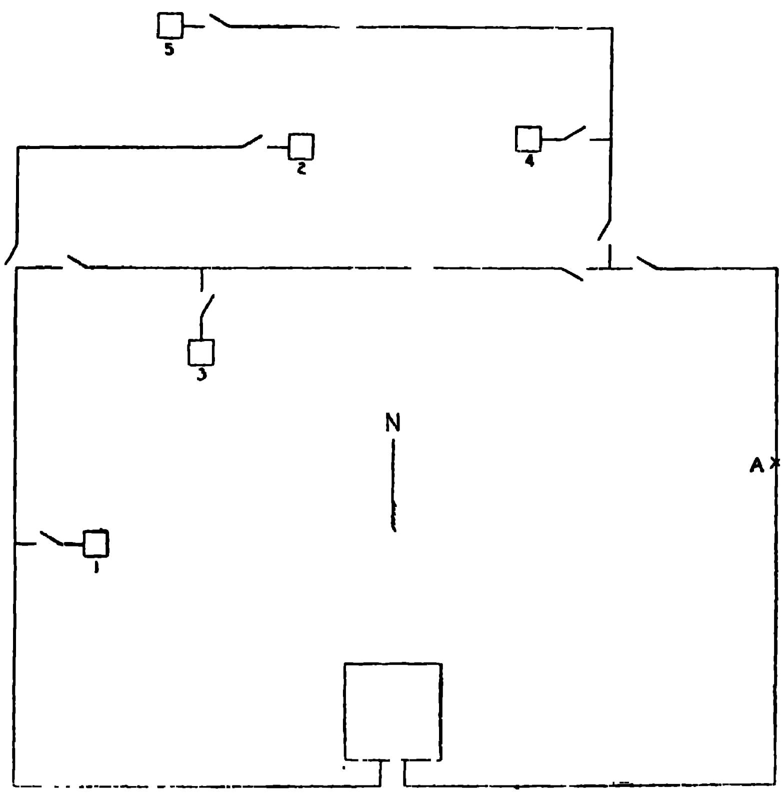


Fig. 31. Use of Sectionalizing Switches

case it or its tap line is in trouble. If the substation is an important one, it should be equipped with three switches at the junction so that it could be supplied from either direction in case of trouble anywhere on the west line.

Disconnectives are usually provided for lightning arresters and transformers so that they may be reached for repair work without interrupting service on the other parts of the system.

INTERCONNECTION OF SYSTEMS

Advantages. The advantages of interconnecting the lines of a given system to provide increased reserve facilities and thus greater reliability have been extended in recent years to the interconnection of adjacent systems of different companies. This has been done in some cases even where the companies were competitors in parts of the territory.

The advantage of such an arrangement is mutual since it enables either company to draw a portion of its supply from the lines of the other company at times when the other company has station and line capacity to spare. This may occur, for instance, when the company requiring assistance has a line down, with no reserve supply available, or a generator out of service for overhauling and not sufficient capacity to carry the load at certain hours; at such times it may draw the required supply from the other system. At other times the conditions may be reversed and the power is returned. If the use of the exchange facilities is of approximately equal value to each company, the energy is exchanged at equal rates, but if the exchange is more advantageous to one company than to the other, the energy is metered in each direction separately and the charge computed according to the readings.

In some cases one system may have a summer peak and the other a fall or winter peak. Interconnection makes the reserve capacity of both companies available for peak purposes under these conditions. This is of particular value in the case of water powers, where there may be differences in the storage supply during different months of the year. The use of an interconnection between two systems tends to improve the load factor of both systems, and thus is an economic benefit to both.

Construction. The construction of interconnecting lines follows the same general principles which determine the character of other transmission lines. In cases where the voltages of the system are the same the connection is accomplished through a switching tower at a point convenient to both. If the voltages are different, transformers must be introduced to bring them together, and this involves a substation installation, which is likely to be of the outdoor type.

OPERATION AND MAINTENANCE

Control of System. The operation of transmission lines is simple until the system becomes interconnected by tie lines and loaded with taps or loops at various points. Under these conditions it has become the general practice to place the control of the entire system under a system operator, often called a "load dispatcher" because of the similarity of his duties to those of the train dispatcher of a railroad.

In such a system the position of every circuit-breaker and disconnective on the transmission system is indicated on a large diagram occupying one wall of the dispatcher's office. The switches are marked by colored pins to indicate whether closed or open and whether the lines on each side of an open switch are out of phase or in synchronism with each other. The position of each switch is kept continuously recorded by telephone reports from substation operators and patrolmen. No switch is opened or closed on any line without notice to the load dispatcher, and in many cases switches are not to be operated except by the direct order of the dispatcher.

These precautions apply both to switching for repair and construction work and to switching for emergency operating conditions and are very necessary for the protection of the apparatus and property of the company as well as for the safety of employes who depend upon the accuracy of the central authority for their safety in working on lines.

The system operator is also charged with working out a daily schedule of line loads which will be most economical and to adjust the daily routine as circumstances may require.

Inspection. An important part of the operation of overhead lines is the periodical inspection of the line by patrolmen. In some cases this is done daily, but usually a weekly or bi-weekly inspection is sufficient. This, however, is dependent upon weather conditions, and it is considered necessary to patrol as soon as possible after a lightning storm or a high wind for the purpose of discovering incipient trouble. Some of the things which are discovered before they have caused an interruption are cracked insulators, broken pins, burned pins or arms, limbs hanging on the wire, kite strings, bale wires, and similar potential causes of trouble.

The discovery of defective insulators is often not possible without the aid of a testing device. Various forms of testing equipment are used but the most common is what is known as a megger, which is a device using a telephone receiver as an indicating instrument. It is readily portable and can be used on either suspension- or pin-type insulators.

The necessity for a testing device is greater on the higher voltages as the probability of failure from insulators which are only slightly defective is much greater on the higher than on the lower voltages.

In some of the larger systems where the continuity of service makes it difficult to take sections of line out of service for repairs, tools and methods have been worked out by which insulators, pins, and crossarms can be replaced with the line alive and carrying load. This is done without excessive risk to linemen or to the continuity of service on lines operating as high as 66,000 volts. The tools are insulated by long wooden handles carefully impregnated and provide for holding the wire clear while it is free from the insulator and for attaching and detaching the wire fastenings, insulators, and other parts which may need replacement.

The patrolling of lines on highways is usually facilitated by the use of suitable means of transportation. Along railroad rights of way in many cases inspections can be made from a train to advantage. Lines running across country must be patrolled afoot or by horse if they are not accessible from adjacent highways.

The frequency of inspection is largely governed by the importance of the service, the reserve available by other routes, and the character of natural hazards such as trees, exposed hilltops, and the like.

RIGHTS OF WAY

Selection of Route. The selection of the route for a transmission line involves various considerations of a practical nature. At lower voltages the usual practice is to follow public highways or secure rights parallel to, and just outside of, a railroad right of way.

The use of highways is generally limited to pole lines at voltages under 50,000, as space for towers is not available. The

consent of the constituted authorities and, in some states, of the owners of a majority of the frontage of the abutting property is required. The highways are often occupied by local and long-distance telephone lines, which tend to introduce complications at crossings and may become the source of complaints of inductive interference. In the selection of highway routes those occupied by telephone lines should therefore be avoided as far as possible.

Where lines are run parallel to a railroad, it is usually possible to secure a more direct route than where highways are followed. Such routes are in some cases not purchased outright but are taken in such form as to include right of access for construction, repair, and maintenance work without depriving the owner of the use of the land for agricultural purposes. This plan is used where the value of the land is high and the owner does not wish to sacrifice its productive power by selling it.

In rough country where the surface is not valuable it is usually preferable to purchase the right of way for important lines. This can usually be done in such a way as to make an approximately straight line. Highways in such country are not numerous and, being made to conform to the topography, are laid out in curves which, if followed, would add materially to the length.

The right of way in wooded country should be wide enough to obviate damage from trees falling near the edge of the right of way. In most cases a width of 50 to 60 feet is necessary for a single line of poles or towers. If two lines of towers are on the same right of way, it should be 100 feet wide.

The right of way is cleared of all trees and obstruction and is sufficiently graded to provide a road for the use of construction crews and patrolmen. If tower lines are used, it is necessary to have a private right of way in order to secure the necessary space for foundations and to permit the use of broad-base structures.

UNDERGROUND LINES

Cables. In the delivery of power from generating stations to substations in the larger cities it is usually necessary that the lines running into the more congested districts be placed underground. In other cases it is desirable to put part of a line

underground, as in crossing a navigable river or in entering a large industrial establishment in which the buildings are closely arranged. For such underground construction lead-covered cables have been found quite satisfactory and are generally used.

If the general distribution system requires the presence of a conduit system, this is used for the transmission cables as well. In case there are several lines going in the same general direction, it is desirable to build a conduit line for the transmission lines, if necessary, in order to secure the advantages of a draw-in system in making repairs; where there are but one or two cables and no conduit system exists, the cable is provided with an armor of steel wire or tape over the lead sheath to protect it from mechanical injury. The cable is then laid in a trench in the bottom of the stream, or in the earth, as the case may be. Such construction is not desirable where the cable must be laid for any considerable distance under the paving, a roadway, or a sidewalk.

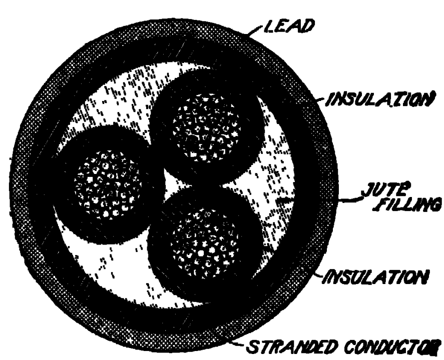


Fig. 32. Section of Polyphase Cable

If there is a probability that excavations may be made across or along the route of the line from time to time, the cable should be further protected from possible injury by a pick by laying a plank above it. This serves as a warning to subsequent excavators, and thus obviates unintentional damage to the cable.

Covers for Cables. The majority of the transmission cables in American cities are in conduit systems and consist of three conductors insulated with oiled paper and encased in one lead sheath, Fig. 32.

The individual conductors are wrapped spirally with strips of oiled paper, a sufficient number of layers being applied to insulate for the voltage to be used. These conductors are then grouped with the necessary jute filler to make a circular cross-section, and an outer belt of oiled paper is put around the whole. The lead sheath is applied by passing the insulated conductors through a

lead press which applies a sheath having a thickness of about $\frac{1}{8}$ inch.

Formerly the oils used for impregnation of the paper were derived from compounds of rosin, but in recent years it has been found that certain mineral oils are preferable to the vegetable oils obtained from rosin. The principal advantage of the mineral oils is that there is less dielectric loss in the cable. At the higher voltages (above 13,000 volts) the charging current of the cable is high, and there is a sufficient loss of energy in the insulation acting as a dielectric to raise the temperature of the cable. The dielectric loss increases with rising temperatures, so that if a cable is loaded heavily, the heating effect is cumulative, and above a certain critical point the temperature continues rising until the insulation is charred and the cable breaks down. With mineral oils the critical point is higher, and the cables may be operated with safety at heavier loads than with rosin oils.

Rubber is not suitable for use on high-voltage cables, as it is not so easy to apply uniformly as is paper or cloth and does not retain its insulating qualities so well. It is also more expensive and is rarely used for transmission lines.

Varnished cambric has found a field of usefulness in cable insulation, as it is less ready to absorb moisture than oiled paper, and it has been used to some extent where there was likelihood of moisture reaching the insulation at terminals or elsewhere. In most cases, however, if cables are provided with proper potheads at terminals and with wiped sleeve joints, there is little danger of moisture entering the cable and paper cable is therefore very extensively used.

Graded Insulation. For voltages above 20,000 the insulation is best applied in the form known as *graded insulation.* For the layer next to the conductor a highly insulating substance, such as a fine grade of rubber, is used, and for the outer layers a lower grade of rubber or paper with a lower dielectric strength. This practice is based on the fact that the fall of potential is more rapid in the immediate vicinity of the conductor than at points farther from its center.

The use of graded insulation reduces the total thickness of insulation, as compared with that required if it is computed on

TABLE XI

Thickness of Insulation on Ungraded Cables

Volts	Thickness Each Conductor (in.)	Over All (in.)
7000	$\frac{5}{32}$	$\frac{4}{32}$
10000	$\frac{6}{32}$	$\frac{4}{32}$
13000	$\frac{6}{32}$	$\frac{5}{32}$
17000	$\frac{7}{32}$	$\frac{5}{32}$
20000	$\frac{6}{32}$	$\frac{6}{32}$
25000	$\frac{10}{32}$	$\frac{8}{32}$

the basis of a given number of mils per 1000 volts evenly distributed. The thickness of insulation on ungraded cables is dependent somewhat on the characteristics of the paper and oils employed and varies somewhat with different manufacturers, but the values given in Table XI are a fair average.

Corrosion of Cable Sheaths. Where cables are subject to corrosive action on the lead sheath, as from alkali in the soil or from other destructive agents, the problem of maintaining service sometimes becomes quite difficult. In the case of electrolysis relief is had by bonding the cable sheaths to water piping by heavy copper cables, thus reducing the difference of potential to a point below the danger line. In the case of isolated sections this is sometimes not practicable, and a measure of protection is gotten by insulating sections of the cable sheath from each other, thus breaking the continuity of the circuit.

Where cables are laid directly in the soil, there are apt to be sections which are in alkali or cinders or other destructive media. In such cases the use of the type of insulation known as "Kerite" has been found of value. This is a secretly made compound of rubber and other material which withstands the action of corrosive elements and lasts remarkably well under exposure to the weather and to underground conditions. It resembles rubber and is spliced in the usual way. It can be used without lead sheath in the earth or in ducts at voltages of 2000 to 13,000 without showing the oxidizing effects which are found in rubber insulation as ordinarily made. It is somewhat more expensive in first cost than lead-sheathed paper cable.

Jointing. The jointing of transmission cables must be done with care and by one who is well trained for the work. For this reason some manufacturers are prepared to install and joint the cable, turning it over to the user ready for service.

The joint between conductors is made by sleeves of such outline as to have no sharp corners which might act as discharge points and thus become the incipient cause of a burnout. The wrapping of tape over the sleeves should be closely made so as to avoid air spaces in the joint. After the insulation has been applied in quantity sufficient to be equivalent to that of the cable, a lead sleeve is wiped to the cable sheath and the air space carefully filled with a high-grade insulating compound. The various operations are illustrated in Fig. 33.

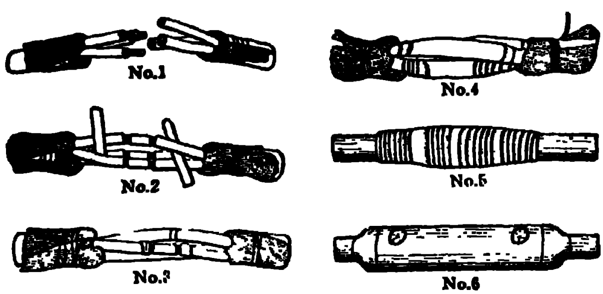


Fig. 33. Operations in Jointing a Three-Conductor Cable

If a tap is made, as is sometimes necessary, the cable is joined at an angle so that the sleeve when completed makes a Y joint. This facilitates the training of the cable and reduces the liability of damage to the joint while placing the cable after the compound in the joint has cooled.

Protective Equipment. The effect of lightning is not felt in underground lines, except where they are brought up a pole to connect to an overhead section. At such points a lightning arrester should be provided on the overhead line to prevent injury to the cable. Short lengths, such as river or boulevard crossings, are more susceptible to damage by lightning than longer sections and should be protected at each end.

Where two or more underground lines are operated in parallel, it is necessary that they be protected by suitable relays. In case a fault develops in one cable, there must be a system of control

which will cut out the faulty cable at each end without interrupting the supply to the cables which are not defective. This is accomplished by relays at each end of the line which are so arranged as to open the circuit breaker at the supply end on overload and to open the breaker at the substation end when energy flows in the reverse direction.

The arrangement of lines in connection with several substations often takes a form shown diagrammatically in Fig. 34. There are radial lines and tie lines in such a combination, the tie lines being those which interconnect the substations.

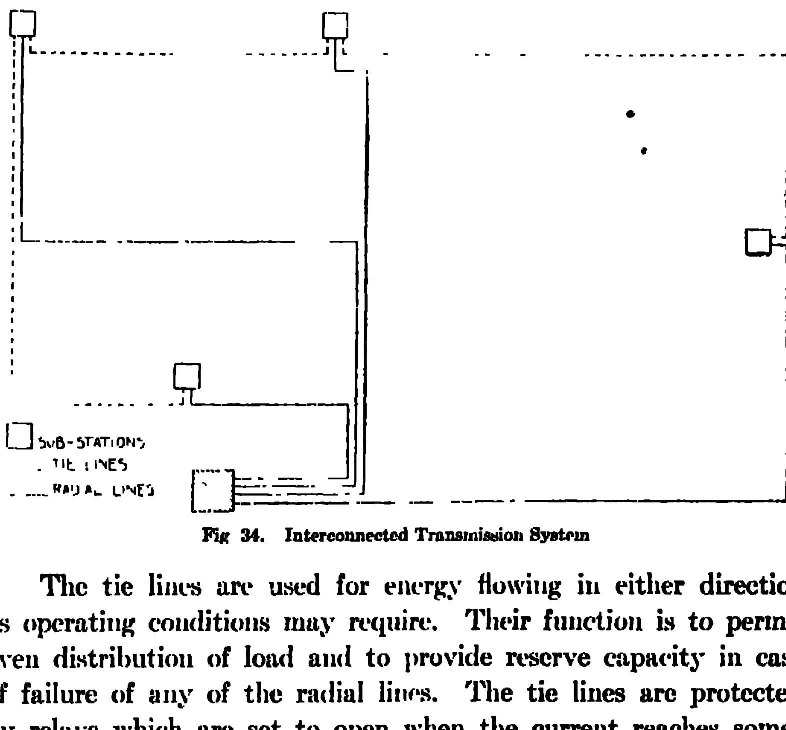


Fig 34. Interconnected Transmission System

The tie lines are used for energy flowing in either direction as operating conditions may require. Their function is to permit even distribution of load and to provide reserve capacity in case of failure of any of the radial lines. The tie lines are protected by relays which are set to open when the current reaches something over twice full-load current. The settings of all relays are made high enough to open only when there is a short-circuit drawing several times the amount of normal rated capacity of the cable. It is not desirable or necessary to set relays low enough to protect against overloads in normal operation, as there is a tendency for them to operate when no emergency exists, thus causing unnecessary interruption of service.

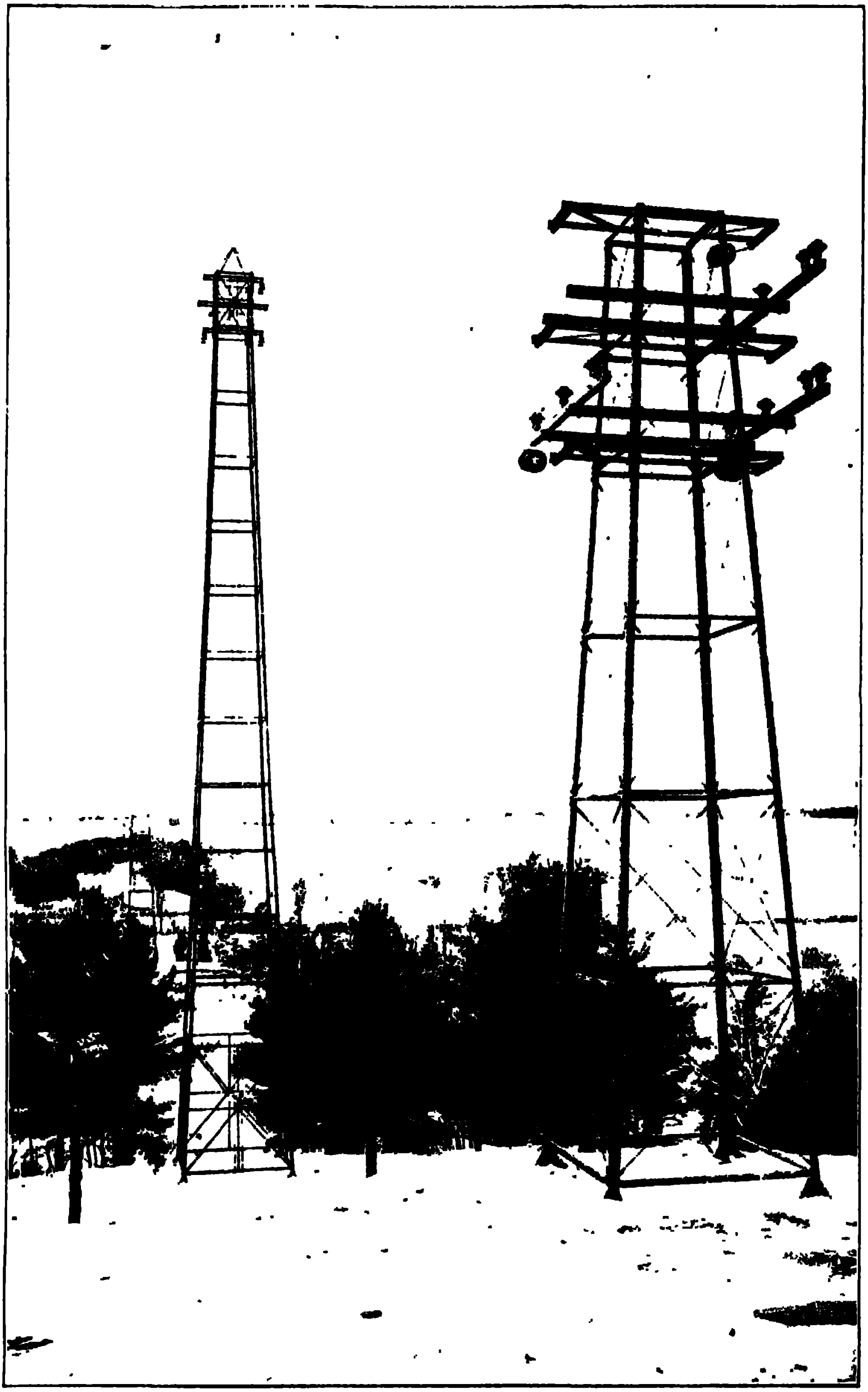
Reliability. The reliability of underground lines is materially better than that of overhead lines, as they are not subject to weather conditions, storms, etc., and when well installed rarely give trouble owing to defects in the cable system. Such defects as occur arise from damage done by mechanical injury, by electrolysis of the lead sheath, or occasionally by burnout under overload, but all these can be held in check without serious difficulty and at less expense than is involved in maintaining overhead lines.

For loads of 2000 kilowatts and larger and at the distances of less than ten miles prevailing in large cities, the investment in underground lines is not excessive and is fully justified by the increased reliability thereby attained.

Transmission in Future. The tendency of transmission lines has ever been upward: upward in voltage and upward in carrying capacity. In the beginning of this phase of electrical development lines at 10,000 volts and having a capacity of less than 5000 kilovolt-amperes were considered advanced practice. Since 1893 voltages have gone from 10 kilovolts to 20, thence to 40 and 66, and in recent years to 110 and 150 kilovolts. At the latter pressures the carrying capacity of the lines has approached 50,000 kilovolt-amperes.

With the development of central-station systems to a point where practically all the power requirements of a community are served by them, loads of 50,000 kilovolt-amperes are becoming increasingly common, and the conditions favor the use of lines of greater capacity and higher voltages. This tendency is furthered by the fact that as voltages go higher the distances of transmission may be increased and the area served by a line may become correspondingly greater.

Accordingly, engineers are studying the practical design of lines to operate at 220,000 volts and to have a capacity of 100,000 kilovolt-amperes or more. While such lines are not likely to be numerous, the realization of this dream of the power engineer is not far in the future.



HIGH TENSION TRANSMISSION LINE CROSSING THE KENNEBEC RIVER NEAR AUGUSTA, MAINE

Courtesy of Archbold-Brady Company

ELECTRICAL DISTRIBUTION

GENERAL FEATURES

Function of Distribution Systems. Electrical distribution systems have been developed as a means of delivering electricity from the central station where it is produced to the points of consumption in the users' premises. Distribution systems are used in large industrial concerns to supply the various buildings with light and power, and in recent years they have been extended to rural communities where electric service is assisting the farmer in his work.

Where users of electricity are grouped together in cities or towns, it is more economical to supply their requirements from a central source of supply than from several small isolated plants. There is enough saved in the cost of the station to pay the cost of installing the distribution system, and the small consumer is thus able to secure from a central station system electric service which he could not afford to have if he had to buy his own generating equipment.

The capacity of the central power plant is much smaller than the aggregate capacity of a large number of small isolated plants would be, since the consumers' hours of use vary greatly, which reduces the load on the central station to a small fraction of the aggregate load that would be placed on the power plants of individual users if each had his own plant. The reduction in the cost of energy in recent years has resulted in the abandonment of many isolated plants of considerable size, and distribution systems have had to be modified to include lines of larger capacity than were formerly used.

PROPERTIES OF CONDUCTORS

Metals as Conductors. All metals are conductors of electricity, but each has its own characteristics of resistance, temperature coefficient, and mechanical strength.

Copper, being among the best conductors and sufficiently plentiful in nature, is the metal most commonly employed for distribution work. Because of the low specific gravity of aluminum it is used in transmission work to some extent. Iron is used as an electrical conductor for rural lines; in railway work where the rails carry the return current to the power house; and in third-rail systems, the supply to the motor cars being so carried.

Area of Cross-Section. The area of the cross-section of a wire is commonly measured in circular mils, 1 circular mil representing the area in square inches of a wire having a diameter of 0.001 inch, or 1 mil; that is

$$1 \text{ cir. mil.} = \frac{\pi}{4}d^2 = 0.785 \times (0.001)^2 \text{ sq. in.}$$

The area of a conductor 1 inch, or 1000 mils, in diameter is therefore 1000^2, or 1,000,000, circular mils, and a conductor having a diameter of 0.5 inch has an area of 250,000 circular mils.

Wire Gages. A wire gage consists of a series of numbers used as a means of identifying the various sizes of wires. The gage numbers are made intelligible by a table giving the diameter of each size, the weight per 1000 feet, the feet per pound, and, in the case of wires used as electrical conductors, resistance data per 1000 feet, etc. In earlier years the different manufacturers adopted their own wire gages, which did not exactly agree. Thus the makers of steel wire had one gage and the makers of copper wire a different one.

Steel Wire Gage. The Washburn & Moen gage was established in 1830 for use in the manufacture of iron and steel wire. The American Steel and Wire Company, upon absorbing the Washburn & Moen Company, adopted its steel wire gage and gave it the name of the new company. In 1912 the U.S. Bureau of Standards made a complete study of wire gages. This report showed that the great majority of steel wire was being made in accordance with the American Steel and Wire gage and that this gage was quite well adapted to the purpose. It recommended this gage therefore as the "steel wire gage" for the United States, and the American Institute of Electrical Engineers adopted this name as standard. Another gage which is used to a limited extent is the Birmingham, or the Stubs, steel wire gage.

TABLE I

Comparison of Wire Gages

No.	Steel Wire (W.& Moen)	American (B.& S)	Birmingham (Stubs)
000000	0.461	..	...
00000	0.430	....	...
0000	0.393	0.460	0.454
000	0.362	0.4096	0.425
00	0.331	0.3648	0.380
0	0.307	0.3249	0.340
1	0.283	0.2893	0.300
2	0.263	0.2576	0.284
3	0.244	0.2294	0.259
4	0.225	0.2043	0.238
5	0.207	0.1819	0.220
6	0.192	0.1620	0.203
7	0.177	0.1443	0.180
8	0.162	0.1285	0.165

American Wire Gage. The American wire gage (A.W.G.) is used exclusively in America for wires intended for use as electrical conductors. It was devised by the Brown & Sharpe Manufacturing Company in 1857 and is often referred to as the B.& S. gage. The American Institute of Electrical Engineers adopted this gage as standard under the name "American wire gage," and this is the term now used by manufacturers of electrical wires in designating their output.

This gage is based upon a simple formula which gives regular gradations in size from largest to smallest. The sizes grow smaller in diameter as the numbers grow larger, thus following the wire drawing process in a general way. The diameter of any wire in the series is 2.005 times the diameter of the sixth size smaller. Thus, No. 0 has a diameter 1.1229 times that of No. 1 and 2.005 times that of No. 6. In areas the ratio of any size to the next smaller size is 1.261, and any size has 2.005 times the area of the third smaller size. The area of No. 0 is 1.261 times that of No. 1 and 2.005 times that of No. 3.

The diameter of wires in inches in the steel, the American, and the Birmingham wire gages are given in Table I.

Edison Gage. In laying out Edison low-tension mains and feeders, it developed that sizes larger than the largest gage numbers would be common. Edison therefore designated conductors by the number of thousands of circular mils of area. Thus a

conductor having an area of 100,000 circular mils was called a 100 conductor, one having 500,000 circular mils was a 500 conductor, and one having 1,000,000 circular mils a 1000 conductor.

Stranded Cables. In the larger conductors the rigidity is so great that it is necessary to subdivide them into a sufficient number of strands to give the necessary flexibility. The strands are arranged in concentric layers about a central core, or they may consist of a "rope lay" made by combining several smaller cables as shown in Fig. 1. The rope lay is not used generally for electrical conductors, its use being limited to extra-flexible cables.

Resistance. The resistance of a conductor depends upon three things: the metal of which it is made; the method of manufacture and purity of the metal; and the temperature at which it carries the electric current.

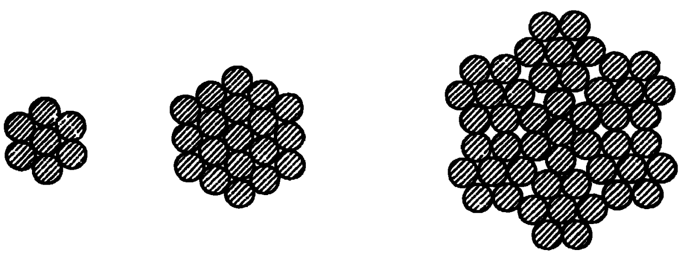


Fig 1 Cable Stranding

The method of manufacture of a metal has a considerable influence upon its resistance. Copper in the form of castings ordinarily contains so much impurity that its resistance is from 25 to 100 per cent higher than that of copper which has been drawn. The resistance of drawn copper is somewhat reduced by annealing after the drawing process.

The resistance of all metallic conductors is increased by an increase in temperature. Carbon affords a notable contrast to metallic conductors in that its resistance decreases with increasing temperature.

Conductivity. The conductivity of a conductor is $\frac{1}{R}$, R being its resistance. For purposes of comparison, conductivity affords a more convenient working basis than resistance, since the higher the conductivity the better the conductor. Copper is made the

TABLE II

Temperature Coefficients of Copper for Different Initial Temperatures (Centigrade) and Different Conductivities

Conductivity (per cent)	a_0	a_{15}	a_{20}	a_{25}	a_{30}	a_{50}
95.0	0.00403	0.00380	0.00373	0.00367	0.00360	0.00336
97.0	0.00413	0.00389	0.00381	0.00374	0.00367	0.00342
97.3	0.00414	0.00390	0.00382	0.00375	0.00368	0.00343
98.0	0.00417	0.00393	0.00385	0.00378	0.00371	0.00345
100.0	0.00427	0.00401	0.00393	0.00385	0.00378	0.00352

basis of comparison, and it is said to have 100 per cent conductivity when its purity and density are such that 1 foot of copper wire having a diameter of 1 mil (0.001 inch) has a resistance of 10.371 ohms at a temperature of 20° C., or 68° F.

Ordinary commercial drawn or rolled copper has a conductivity of 96 to 99.5 per cent of this value, and electrolytic copper may have a conductivity of over 100 per cent. It is usual to specify a conductivity of about 98 per cent when selecting cables for heavy currents and important service.

Temperature Coefficient. The variation of the resistance of a conductor with the rise or the fall of its temperature follows a definite law which may be expressed in the form

$$R_t = R_{t_1}\ [1+a_{t_1}\ (t-t_1)]$$

in which R_{t_1} is the known resistance at t_1 degrees C.

The value of a_{t_1}, the temperature coefficient, varies with the starting point. It is higher for resistances measured initially at 5 degrees, for instance, than for those measured initially at 20 or 30 degrees. It also varies with the conductivity of the metal.

The values of a_{t_1} for annealed copper as published by the U. S. Bureau of Standards are given in Table II.

The values given for a conductivity of 100 per cent may be used for annealed, or soft-drawn, wire. The values given for 97.3 per cent conductivity in the table should be used for hard-drawn wire.

Example. With an annealed copper conductor having a resistance of 0.2 ohm at 20° C. the resistance at 45° C. according to the formula previously given would be

$$R=0.2\ [1+0.00393\ (45-20)]=0.2\ (1.0982)=0.2196 \text{ ohm}$$

TABLE III

Properties of Annealed Copper Wire

Size A.W.G.	Diameter (mils)	Cross-Section		Weight per 1000 Feet (lb.)	Weight per 1000 Feet, Weather-proof (lb.)	Resistance per 1000 Feet (ohms)	
		Circular Mils	Square Mils			20° C.	50° C.
0000	460.0	211600	0.1662	640.5	741	0.04901	0.05482
000	409.6	167800	0.1318	570.9	598	0.06180	0.06912
00	364.8	133100	0.1045	402.8	485	0.07793	0.08716
0	324.9	105500	0.08289	319.5	382	0.1002	0.1099
1	289.3	83690	0.06573	253.3	312	0.1264	0.1386
2	257.6	66370	0.06213	200.9	254	0.1563	0.1748
3	229.4	52640	0.04134	159.3	199	0.1970	0.2204
4	204.3	41740	0.03278	126.4	163	0.2485	0.2779
5	181.9	33100	0.02600	100.2	132	0.3133	0.3504
6	162.0	26250	0.02062	79.46	109	0.3951	0.4418
7	144.3	20820	0.01635	63.02	88	0.4982	0.5572
8	128.5	16510	0.01297	49.98	74	0.6282	0.7025
9	114.4	13090	0.01028	39.63	60	0.7921	0.8860
10	101.9	10380	0.008155	31.43	50	0.9989	1.117
11	90.74	8234	0.006467	24.92	42	1.260	1.409
12	80.81	6530	0.005129	19.77	34	1.588	1.776
13	71.96	5178	0.004067	15.68		2.003	2.240
14	64.08	4107	0.003225	12.43	24	2.525	2.824
15	57.07	3257	0.002558	9.858		3.184	3.562
16	50.82	2583	0.002028	7.818	19	4.015	4.491

TABLE IV

Properties of Annealed Stranded Copper Cables

Size CM	Weight per 1000 Feet (lb.)	Standard Strands			Resistance per 1000 Feet (ohms)	
		Number of Wires	Diameter of Wires (mils)	Outside Diameter (mils)	25° C.	65° C.
2000000	6180	127	125.5	1631	0.00539	0.00623
1500000	4630	91	128.4	1412	0.00719	0.00839
1000000	3090	61	128.0	1152	0.0108	0.0125
750000	2320	61	110.9	998	0.0144	0.0166
600000	1850	61	99.2	893	0.0180	0.0208
500000	1540	37	116.2	814	0.0216	0.0249
400000	1240	37	104.0	728	0.0270	0.0311
350000	1080	37	97.3	681	0.0308	0.0356
300000	926	37	90.0	630	0.0360	0.0415
250000	772	37	82.2	575	0.0432	0.0498
A.W.G.						
0000	653	19	105.5	528	0.0510	0.0589
000	518	19	94.0	470	0.0643	0.0742
00	411	19	83.7	418	0.0811	0.0936
0	326	19	74.5	373	0.102	0.118
1	258	19	66.4	332	0.129	0.149
2	205	7	97.4	292	0.163	0.188
3	163	7	86.7	260	0.205	0.237
4	129	7	77.2	232	0.258	0.298
5	102	7	68.8	206	0.326	0.376
6	81	7	61.2	184	0.411	0.475

With a hard copper wire having a resistance of 0.2 ohm at 20° C. the resistance at 45° C. would be

$$R = 0.2\,[1 + 0.00382\,(45 - 20)] = 0.2\,(1.0955) = 0.2191 \text{ ohm}$$

Mechanical Properties of Copper. The tensile strength of copper varies with its physical condition. Annealed wire breaks at 32,000 to 37,000 pounds per square inch in the larger sizes and at 35,000 to 40,000 pounds in the smaller sizes. Hard-drawn wire breaks at about 50,000 pounds per square inch in the larger sizes and at 65,000 pounds per square inch in the smaller sizes.

The size, weight, and resistance of the sizes of solid wire in general use in distribution are given in Table III, and similar data for stranded cables up to 2,000,000 circular mils in Table IV.

DESIGN OF CIRCUITS

Problem of Designing Circuit. The function of a conductor being to convey electrical energy from the source of supply to the consuming device, it must be of such size that it will not absorb too great a percentage of energy or become overheated. The problem of designing a circuit is therefore one of determining what size of conductor should be used to limit the loss of voltage to a specified amount when distance and current strength are known, and also of determining whether the size needed for the specified voltage drop is sufficient to carry the current safely.

DROP IN VOLTAGE

Direct-Current Circuits

Factors Affecting Drop. In d.c. circuits the current and the resistance are the only factors affecting the drop in voltage. The resistance of a mil-foot of pure annealed copper at 68° F. being 10.4 ohms, that of a conductor D feet long and M circular mils in area is

$$R = \frac{D \times 10.4}{M}$$

The drop E with current I therefore is

$$E = IR = \frac{I \times D \times 10.4}{M} \text{ volts}$$

If both conductors in the circuit are of the same size, the total drop is twice the drop in one conductor; if they are not of the

same size, the drops in the different sizes must be computed separately and added together.

The calculation of the total drop in the two wires of the circuit at any load may also be readily determined, when the size of the conductor is already fixed, by the use of the formula

$$E=\frac{2IDR}{1000}$$

in which R is the resistance per 1000 feet of conductor.

Example. A circuit of No. 0000 cable, 500 feet in length, is to carry a load of 190 amperes; what will be the line drop? The resistance of No. 0000 conductor, Table III, is 0.049 ohm per 1000 feet and D equals 500 feet. The drop is therefore

$$E=\frac{2\times190\times500\times0.049}{1000}=9.3 \text{ volts}$$

Calculation of Size of Wire. From the first equation for drop may be obtained the following equation for area in circular mils:

$$M=\frac{I\times D\times10.4}{E}$$

Example. A two-wire circuit is to carry a load of 100 amperes a distance of 300 feet with a drop of 5 volts. What size of conductor must be used?

$$M=\frac{2D\times I\times10.4}{E}=\frac{2\times300\times100\times10.4}{5}=124800 \text{ cir. mils}$$

The nearest size is No. 00 A.W.G., which should be used.

Three-Wire Direct-Current Circuits. In making calculations for a three-wire Edison circuit, separate computations are made for each conductor if the load is appreciably unbalanced.

Example. A circuit 1500 feet long having two No. 0000 A.W.G. outer wires and a No. 0 neutral carries a load of 150 amperes on the positive side and 110 amperes on the negative side; what is the drop on each side of the circuit? From Table III the resistance of No. 0000 wire is 0.049 ohm per 1000 feet of conductor, and that of No. 0 wire is 0.0981 ohm. The drop on the positive wire is

$$E=IR=150\times1.5\times0.049=11.0 \text{ volts}$$

and the drop on the negative wire is

$$E=IR=110\times1.5\times0.049=8.07 \text{ volts}$$

The current on the neutral being 150−110, or 40 amperes, the drop on the No. 0 neutral wire is

$$E=IR=40\times1.5\times0.10=6.0 \text{ volts}$$

The total drop at the end of the circuit is determined thus: The drop on the heavier loaded wire plus the drop on the neutral wire is the total drop on the

heavier loaded side. In this case this is the positive side, and the total drop is 11+6, or 17 volts. The total drop on the lighter loaded side is the difference between the drop on the lighter loaded wire and that on the neutral. In this case it is 8.07−6, or 2.07 volts. If the bus pressure were 120 volts at the point of supply, the pressure at the end of the line would be 120−17, or 103 volts on the positive side and 120−2.07, or 117.93 volts on the negative side.

It is therefore important that the load on a three-wire circuit be kept balanced as nearly as possible in order that the pressure may not be too far from the desired standard. In this case if the load were balanced at 130 amperes per side, the drop would be

$$E = IR = 130 \times 1.5 \times 0.049 = 9.55 \text{ volts}$$

and the pressure on each side at the end of the line would be 120−9.55, or 110.45 volts.

Alternating-Current Circuits

Factors Affecting Drop. In an a.c. circuit voltage drop is caused by the combined effect of resistance and inductive reactance. The component of drop due to resistance is governed by the laws which govern d.c. circuits and is in phase with the current. The component of drop due to reactance is a counter-electromotive force set up by the magnetic field as it reverses with each alternation; this back-electromotive force is a quarter cycle behind the current wave. The resistance drop and the reactance drop may be represented, therefore, by two sides of a right triangle, Fig. 2. The reactance of a circuit increases with the increase in the separation of the conductors of the circuit or with the introduction of iron into the magnetic field, since in either case the number of lines of force linked with the circuit is increased.

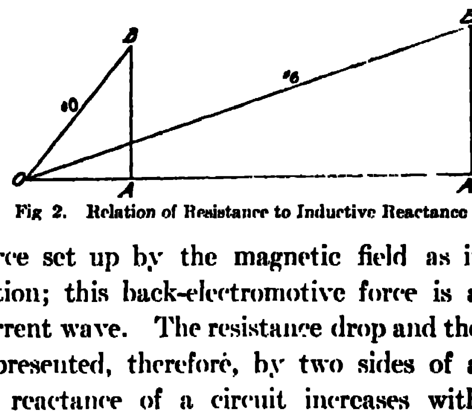


Fig. 2. Relation of Resistance to Inductive Reactance

In Table V is given the reactance drop in volts per ampere, for 1000 feet of conductor, for the distances of separation and sizes of wire commonly used in distribution work.

Example. A single-phase circuit 10,000 feet long operates at 60 cycles and carries a load of 100 amperes with No. 0 wires 12 inches apart. What are the values of the inductive and the ohmic components of drop? The reactance per 1000 feet per ampere per wire, designated by X, for No. 0 wires 12 inches apart is 0.1043, Table V. The resistance is 0.10 ohm per 1000 feet. The inductive component of the circuit is therefore

TABLE V

Reactance Drop for Various Amounts of Separation and Sizes of Wires

Size A.W.G.	Area (cir. mils)	Volts Drop per Ampere per 1000 Feet per Wire at 60 Cycles — Distance between Centers										
		½ Inch	1 Inch	2 Inches	3 Inches	6 Inches	12 Inches	18 Inches	24 Inches	36 Inches	48 Inches	60 Inches
....	1000000			.		0.063	0.0784	0.0877	0.0943	0.1036	0.1102	0.1153
....	500000	.		. ..	..	0.071	0.0864	0.0957	0.1023	0.1116	0.1182	0.1233
....	350000	. .		. .		0.0746	0.0907	0.0998	0.1064	0.1157	0.1223	0.1274
0000	211600	0.0328	0.0394	0.0553	0.0646	0.0805	0.0964	0.1057	0.1123	0.1216	0.1282	0.1333
000	167800	0.0355	0.0421	0.058	0.067	0.0832	0.0991	0.1084	0.1150	0.1242	0.1308	0.1360
00	133000	0.0381	0.0447	0.060	0.070	0.0858	0.1017	0.1110	0.1176	0.1269	0.1335	0.1386
0	105500	0.0408	0.0474	0.0633	0.0726	0.0885	0.1043	0.1136	0.1202	0.1295	0.1361	0.1412
1	83700	0.0435	0.0501	0.0659	0.0752	0.0911	0.1070	0.1163	0.1229	0.1322	0.1388	0.1439
2	66400	0.0461	0.0527	0.0686	0.0779	0.0938	0.1097	0.1190	0.1256	0.1348	0.1414	0.1466
4	41700	0.0514	0.0580	0.0739	0.0832	0.0991	0.1150	0.1243	0.1309	0.1402	0.1468	0.1519
6	26200	0.0567	0.0633	0.0792	0.0885	0.1044	0.1203	0.1296	0.1362	0.1455	0.1521	0.1572
8	16500	0.0621	0.0687	0.0845	0.0938	0.1097	0.1256	0.1349	0.1415	0.1508	0.1574	0.1625
10	10400	0.0674	0.074	0.0898	0.0991	0.1151	0.1309	0.1402	0.1468	0.1561	0.1627	0.1678

TABLE VI

Corresponding Values of Resistance and Inductance Factors

Resistance Factor (per cent)	50	60	65	70	75	80	85	90	95	97.5	100
Inductance Factor (per cent)	86.6	80	76	71	66	60	53	44	31	22.2	0

$$X=2D\times I\times\frac{0.1043}{1000}=2\times 10000\times 100\times\frac{0.1043}{1000}=208.6 \text{ volts}$$

The ohmic component is

$$R=2\times 10000\times 100\times\frac{0.10}{1000}=200 \text{ volts}$$

The impedance drop in the circuit is found by the equation

$$\text{Impedance drop}=\sqrt{(209)^2+(200)^2}=289 \text{ volts}$$

which is represented by OB in Fig. 2. The length of the line OA in Fig. 2 is proportional to the resistance component, that of AB represents the inductive component, and that of OB the resultant of the two.

If the circuit consisted of two No. 6 wires, the resistance component would be $2\times 10\times 100\times 0.395$, or 790 volts, the inductive component $2\times 10\times 100\times 0.12$, or 240 volts, and the impedance drop $\sqrt{(790)^2+(240)^2}$, or 827 volts. The diagram for the impedance drop in Fig. 2 is $OA'B'$. It is apparent that the ratio of resistance to inductance decreases as the size of wire is increased, so that increasing the size for the purpose of reducing the pressure drop becomes less effective in the large sizes.

Resistance and Inductance Factors. The resistance factor of a circuit is the ratio of its resistance to its impedance. Likewise the inductance factor is the ratio of the inductive reactance to the impedance. The sum of the squares of these two factors is unity. The values of the inductance factor which correspond to various common values of the resistance factor appear in Table VI.

Single-Phase Line Drop. In an a.c. circuit the pressure drop is determined from the resistance and the inductance components in conjunction with the power factor of the load which the circuit is carrying.

Referring to Fig. 3, the line OE represents the pressure delivered; OR is the component of OE which is doing useful work; ER is the inductive component of the pressure, which causes the current to be out of phase with the impressed voltage at the load; EL is the resistance component of the line drop; and LP is the inductive component of the line drop. The resistance component

of the line drop EL and the power component of the impressed load voltage OR are in phase with each other, and the inductive components ER and LP are in phase. The resultant OP is the line voltage necessary to deliver a pressure OE at the end of the line. The net line drop is the numerical difference between OP and OE. In the case of a noninductive load, such as incandescent lamps, the inductive component ER disappears, and the impressed voltage at the lamps OE takes the position OF. The impressed line pressure necessary to deliver OF at the lamps is ON, or the resultant of OM (which equals $OF+EL$) and MN (which equals LP); and the drop is the numerical difference between ON and OF.

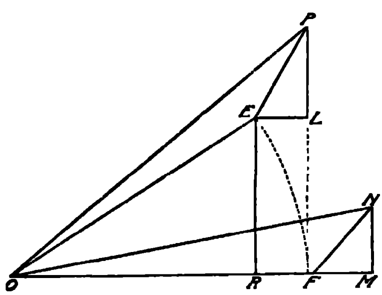


Fig. 3. Alternating-Current Line Drop with Inductive Load

Example. Given a load of 100 amperes of 2200 volts, single-phase, delivered at the end of a two-wire line of No. 0 copper wire, 4500 feet long, with wires 12 inches apart, a frequency of 60 cycles, and a power factor of 80 per cent, what is the line drop? The power factor being 80 per cent, the corresponding inductance factor is 60 per cent, Table VI. Using these values

$$OR = 0.80 \times 2200 = 1760 \text{ volts}$$
$$ER = 0.6 \times 2200 = 1320 \text{ volts}$$

The resistance drop per 1000 feet per ampere for No. 0 wire is 0.10 volt. The total line resistance drop is therefore

$$EL = 2 \times 0.10 \times 4.5 \times 100 = 90 \text{ volts}$$

The inductive drop per 1000 feet per ampere for 12-inch centers is 0.1043 volt, and therefore

$$LP = 2 \times 0.1043 \times 4.5 \times 100 = 94 \text{ volts}$$

The total resistance component is $OR+EL$, or 1760+90, which equals 1850 volts, and the total inductive component is $ER + LP$, or 1320+94, which equals 1414 volts. The resultant of these two is

$$OP = \sqrt{(1850)^2+(1414)^2} = 2327 \text{ volts}$$

This is the pressure necessary to deliver 2200 volts at the end of the line. The net line drop is, therefore, 127 volts, or 5.8 per cent of the received voltage.

If a lighting load of 100 amperes at 100 per cent power factor were being carried, the inductance factor ER would be zero and ON would be

$$\sqrt{(2290)^2+(94)^2} = 2291 \text{ volts}$$

At 100 per cent power factor, therefore, the drop would be 91 volts.

Two-Phase Line Drop. In the case of a two-phase four-wire circuit the drop is computed for each phase independently, using the method given above.

In a two-phase three-wire system having the load connected between the outer phase wires and the neutral, or common, phase wire the inductive drop on the neutral produces an *unbalanced pressure* at the load end, which cannot be readily calculated.

Three-Phase Line Drop. In a three-phase three-wire circuit with an approximately balanced load the drop at the end of the line is 1.73 times the drop in each wire.

Example. With a No. 0 circuit, carrying 100 amperes a distance of 4500 feet the single-phase drop at 80 per cent power factor was found in the single-phase example to be 127 volts, or 63.5 volts per conductor. On a three-phase circuit the drop is therefore 63.5×1.73, or 109.8 volts, which is practically 5 per cent.

At 220 kilovolt-amperes, which was the load assumed on the single-phase circuit, the current on a three-phase circuit would be

$$I = \frac{220000 \times 1.73}{3 \times 2200} = \frac{173.3}{3} = 57.7 \text{ amperes}$$

Therefore for the same load the drop on the three-phase circuit would be

$$E = \frac{57.7}{100} \times \frac{127}{2} \times 1.73 = 63.5 \text{ volts}$$

This is the same as the drop on one wire for the single-phase circuit.

Relation between Three-Phase and Single-Phase Circuits. According to the relation brought out in the example the following simple rule for finding the drop on a three-phase balanced circuit may be used: *Take one-half the load, find the single-phase current for the half load and calculate the drop for the single-phase current. This will give the drop for the three-phase circuit.* With unbalanced loads the calculation of line drop cannot be computed accurately by any simple rule. However, the rule for balanced circuits is sufficiently accurate for practical purposes in most cases, if the unbalance does not exceed 15 per cent.

Where three-phase circuits are arranged so that all lighting is on one phase, they may be treated as single-phase circuits unless the power load is more than one-half the total load on the circuit.

Three-Phase Four-Wire Line Drop. Since the transformers are connected from phase wire to neutral on three-phase four-wire systems, only the drop on the phase wires is to be determined

if the load is balanced. This is found by considering the phase wire as one side of a single-phase circuit and computing the drop according to the method given for single-phase line drop.

Example. A No. 0 four-wire circuit, 9000 feet long, carries a balanced load of 150 amperes at 2200 volts, 60 cycles, and 80 per cent power factor at an average spacing of 12 inches; what is the line drop? The resistance component of the drop is $150\times9\times0.10$, or 135 volts. The inductive component of the drop is $150\times9\times0.1043$, or 141 volts. The pressure necessary to maintain 2200 volts at the end of the line is

$$E=\sqrt{(1760+135)^2+(1320+141)^2}=2390 \text{ volts}$$

Hence the drop on each phase is $2390-2200$, or 190 volts, which equals 8.6 per cent.

Relation between Drop in Balanced and in Unbalanced Loads. With unbalanced load the drop for the neutral wire must be calculated in the same way and plotted in a diagram showing it in its proper phase relation. This, however, cannot be done by any simple rule, and the graphic solution cannot be made very accurate in practical cases.

With one phase open the current of the other two phases returns by the neutral, and under such circumstances the drop is about 55 per cent more than with balanced load. For instance, if the circuit has a drop of 10 per cent when approximately balanced, it will have a drop of 15.5 per cent when one phase is open or 20 per cent when two phases are open.

CURRENT-CARRYING CAPACITY

Factors Affecting Current-Carrying Capacity. The energy absorbed by a circuit I^2R is dissipated in the form of heat and tends to raise the temperature of the conductor. The maximum current-carrying capacity of a conductor is dependent upon whether it is installed in open air, in conduit, or underground. The character of the insulation is also a factor, since certain kinds of insulation may be safely operated at higher temperatures than others. In Table VII is given the current-carrying capacity of wires and cables under various conditions.

The insulation of rubber-covered conductors should not be operated regularly at temperatures above about 50° C., or 122° F. Weatherproof and other fibrous types of insulation may be operated at temperatures as high as 65° to 70° C., or 149° to 158° F.

TABLE VII

Current-Carrying Capacity of Wires and Cables Under Various Conditions

Size A.W.G.	National Electrical Code		Lead-Covered Cables		
			Single-Conductor		Three-Conductor Paper Insulation (45° C rise) (amp.)
	Rubber Insulation (amp.)	Slow-Burning Insulation (amp.)	Rubber Insulation (30° C rise) (amp.)	Paper or Cambric Insulation (40° C rise) (amp.)	
14	15	20	.		
12	20	25			.
10	25	30	20	22	
8	35	50	30	34	26
6	50	70	50	56	48
4	70	90	78	87	68
3	80	100	98	110	81
2	90	125	121	134	93
1	100	150	145	160	110
0	125	200	169	187	132
00	150	225	192	210	150
000	175	275	245	270	190
0000	225	325	285	315	225
CM					
250000	235	350	320	360	255
300000	275	400	370	415	300
400000	325	500	460	515	370
500000	400	600	550	605	.
750000	525	800	750	830	
1000000	650	1000	900	1030	...
1500000	850	1360	1200	1450	
2000000	1050	1670	1400	1590	...

Current-Carrying Capacity of Underground Cables. The rise of temperature of underground cables depends upon the amount of energy liberated by all the cables in the duct line and upon the ability of the cables and ducts to radiate the heat to the surrounding earth.

The radiating capacity of cables in the *central ducts* of a large underground line is less than that of the cables in the *peripheral ducts*, and the temperature of the former tends to become higher when the ducts are well filled. In a nine-duct line the rating of a cable should be reduced about 15 per cent from its capacity in a four-duct line; while in a sixteen-duct line

it should be reduced about 40 per cent. This is true only when there are working cables in all the ducts of the line.

The carrying capacity of *multiple-conductor cables* is less than that of *single-conductor cables* of the same size because of the larger energy loss in proportion to the radiating surface. Duplex cable has about 90 per cent of the carrying capacity of single-conductor cable; concentric cable, 80 per cent; and three-conductor cable, 75 per cent. The maximum temperature at which paper or cambric should be operated is about 65° C., or 149° F. The temperature may be pushed above this figure occasionally for a short time, but if paper is operated continuously above 65° C., it will be injured.

CLASSIFICATION OF DISTRIBUTION SYSTEMS

Bases of Classification. Distribution systems may be classified in three ways: as to the character of the current, that is, direct or alternating (referred to as d.c. and a.c. respectively); as to method of connection, series or multiple; and as to number of wires, phases, voltage, etc.

Direct-current circuits are operated at the voltage required for use at lamp sockets or motor terminals. This is usually about 110–220 volts, three-wire, for general purposes or 550 volts for power and street railway service.

Alternating-current circuits are operated at about 2200 volts for general distribution purposes. The voltage required at the lamps is derived by the use of transformers located near the consumers' premises. This class of circuits is used very generally for distribution in cities and towns.

Alternating-current primary circuits are single-phase two-wire; two-phase three- or four-wire; or three-phase three- or four-wire.

The frequency of a.c. circuits is usually 60 cycles per second, but 25-cycle systems are in general use for electric railway and other d.c. service. There are also certain non-standard systems in America operating at 30, 33, 50, 62.5, and 66 cycles, these having been adopted before frequencies had become standardized at 60 and 25 cycles. The earliest a.c. systems were operated at 125 or 133 cycles, and some of these are still in service in the smaller towns.

Series systems are those in which the lamps are all in series and the *current* in the circuit is regulated to be kept at 6.6 or 7.5 amperes constantly while the pressure is varied as lamps are added. These are sometimes called *constant-current* systems. Lamps are turned off by short-circuiting them.

Multiple systems are those in which the lamps are all in multiple and the *pressure* is maintained constant while the current varies with the load. Lamps are turned off by open-circuiting the branch leading to the lamp or group of lamps. These are called *constant-potential* circuits.

ADVANTAGES AND DISADVANTAGES OF VARIOUS SYSTEMS

Series Systems

Small Conductor Possible. The principal advantage of the series system is that it is operated at a current of about 7 amperes, which permits the use of a conductor as small as the mechanical

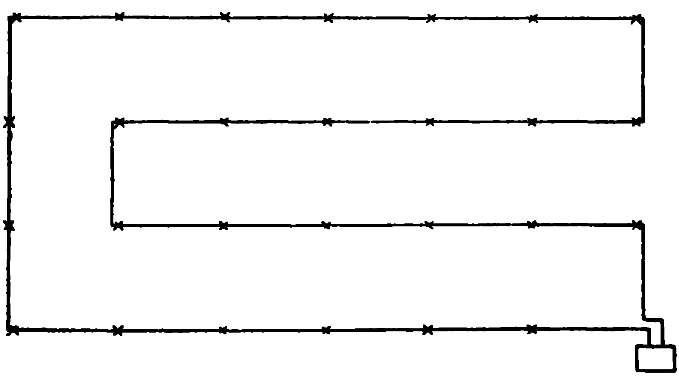


Fig. 4 Open Loop Series Circuit

requirements will permit, usually No. 6 or No. 8. This makes it possible to cover a considerable mileage of street lighting with a minimum cost for the conductors.

Disadvantages. The fact that all lamps are in series makes it a high-voltage system and therefore not so well suited to the general lighting of buildings. It is also subject to the inherent disadvantage that a break anywhere in the circuit puts out the entire circuit. With the a.c. series circuit this is partially obviated by the use of series transformers for individual lamps or groups of lamps which are so designed that a break in the sec-

ondary circuit of the series transformer does not open the main circuit. This also insulates the lamp circuit from the main circuit and makes it safer to work on lamp poles where circuits are underground and lamp posts are iron.

Types of Circuits. *Open-Loop Circuit.* Two general types of arrangement are employed in laying out series circuits, the *open-loop* and the *parallel-loop* circuits. In the open-loop circuit, Fig. 4, the lamps are connected by following the shortest available route, without reference to the separation from the return conductor. This permits a minimum length of circuit, but it is difficult to test for a break, or open circuit, in the line. In a.c. circuits this method of connection also tends to increase interference with telephone systems.

Parallel-Loop Circuit. The parallel-loop circuit, Fig. 5, is laid out so as to be near the return conductor. This affords

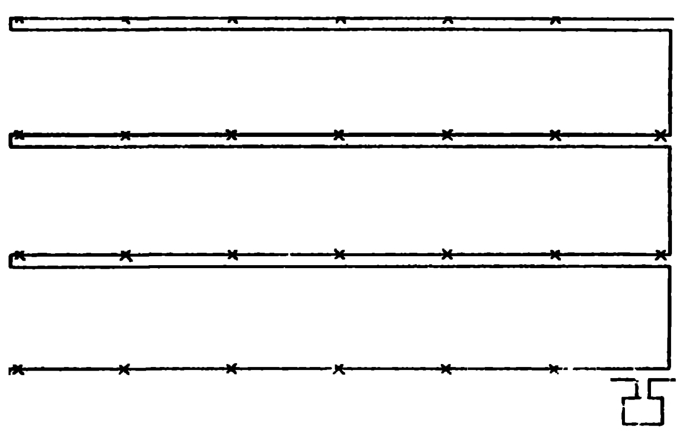


Fig 5 Parallel Loop Series Circuit

frequent opportunity for test and minimizes inductive disturbances but usually requires a greater mileage of conductor than the open-loop circuit. A combination of parallel loops with small open loops may often be used to advantage.

Use of Series Transformer. The a.c. series circuit with lamps grouped on series transformers is shown in Fig. 6. With this arrangement the series transformer is located at a conveniently accessible point on the main series circuit, and the secondary circuit is carried thence to the lamps to be supplied. These may

be a single cluster of decorative street lamps on an ornamental post or a small circuit of lamps in a public square, small park, or similar open space. The voltage on the secondary circuit depends on the amount of energy taken by the group, but it is usually kept below 750 volts.

The series transformer is protected by a film cutout, which punctures and short-circuits the secondary in case of an open

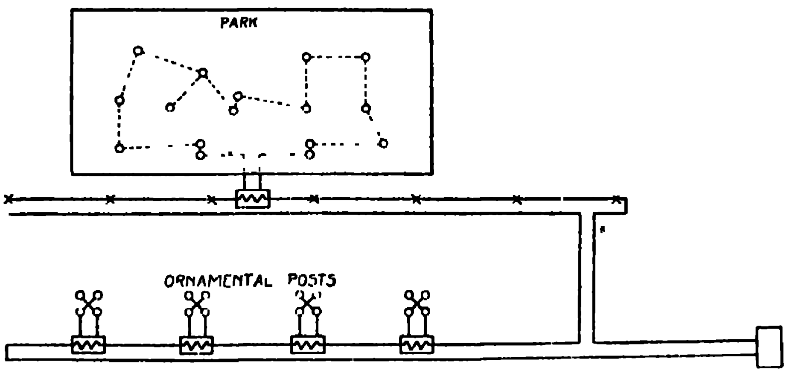


Fig. 6. Series Circuit with Series Transformers

circuit therein. This protects the series transformer from overheating, and the disturbance on the secondary in no way interferes with the service on the main circuit.

Multiple Systems

Direct-Current System. *Advantages.* The d.c. system finds its largest field of usefulness in central business districts where the load is dense and the distance from substation to consumer averages not over 1500 feet. Under such conditions the total cost of installation is not excessive, and where the lines are heavy enough to require underground construction, the heavy cables are more readily operated with direct than with alternating current.

The storage battery, which is most available with this system, affords a means of protection against interruption to service which is of great value in such districts. The d.c. motor is better suited to the operation of elevators, printing presses, and other variable speed machinery than is the a.c. motor, and this class

of service is found in central business districts in considerable quantity.

Disadvantages. The great disadvantage of the d.c. system is the fact that the voltage is low and the currents are therefore very large as compared with those found in a 2200-volt system with similar loads. The radius of distribution is limited to an average of about 1500 feet for a loss of 10 per cent at full load on the feeders. The longest feeder is limited to about 2500 feet, and such feeders cannot be loaded up to full carrying capacity without an excessively high bus pressure at the station. The a.c. system should therefore be employed where the distances are too great for satisfactory d.c. operation.

Efficiency. The operating efficiency of d.c. systems compares very favorably with that of a.c. systems, since the transformer

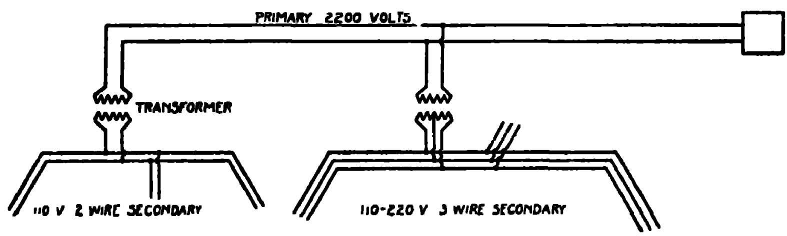


Fig. 7. Single-Phase Circuit

core losses must be supplied continuously in an a.c. system, whereas the higher copper losses of the d.c. system exist only during the time when the load is heavy. The total twenty-four-hour losses are therefore not greatly different, other things being equal.

Location of Station. Where electricity is supplied from a d.c. generating station to the territory in its immediate vicinity, it is necessary that the station be located as near the center of the load as is possible. This is usually not consistent with a location which is most favorable for the economical supply of fuel and water.

Alternating-Current System. *Single-Phase System.* The single-phase system is made up of two-wire feeders and mains, usually operated at 2200 volts, Fig. 7, the mains being of No. 6 or No. 8 wire, the smallest sizes which it is safe to use on over-

head construction for mechanical strength. Since but two wires are required, this is the cheapest system to install for lighting and small power, in spite of the fact that the feeders require 33 per cent more copper than equivalent three-phase feeders at the same voltage.

The principal disadvantage of the system is that single-phase motors are more complicated and expensive than polyphase motors and produce more disturbance of line pressure in starting. The single-phase system is therefore not generally used for power supply except where motors are of less than 5-hp. capacity.

Two-Phase Four-Wire System. Two-phase systems are made up by combining two single-phase systems in a quarter-phase relation, thus making up a four-wire system, or by using a three-wire system in which one conductor of each phase is common,

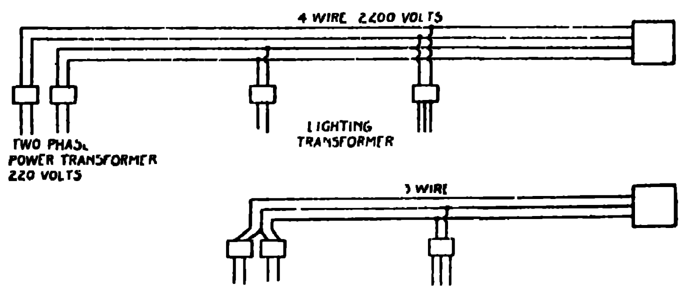


Fig. 8. Two-Phase Circuit

Fig. 8. The four-wire system is substantially the same as a single-phase system, except that two-phase motors may be used. The principal advantages of two-phase systems are that there are only two phases to keep balanced and only two transformers are required to supply polyphase energy to motors.

Two-Phase Three-Wire System. In a two-phase three-wire system the current in the common, or neutral, conductor is 1.414 times the current in the outer conductors with balanced load. When all conductors are the same size, the copper required is 75 per cent of that needed for a four-wire system. When the neutral is 40 per cent larger than the outer conductors, the amount of copper required is 85 per cent of that needed for a single-phase system or a four-wire two-phase system. In the primary mains, which are all the same size, the two-phase three-

wire system is as economical of copper as the three-phase three-wire system. The line drop in the two phases is not the same, making voltage regulation difficult unless line-drop compensators are employed. The three-wire circuit cannot be used where the mid-points of the quarter-phase generator windings are tied together, as is the case in some machines.

Three-Phase Three-Wire Systems. A three-phase three-wire system, Fig. 9, is commonly employed for general distribution since it is readily derived from a three-phase transmission system; it is also well suited to power distribution and requires but 75 per cent as much copper in the feeder system as an equivalent single-phase system. The three-wire distributing mains are usually carried only where motor service is required, the lighting service being taken on single-phase branches from the three-phase

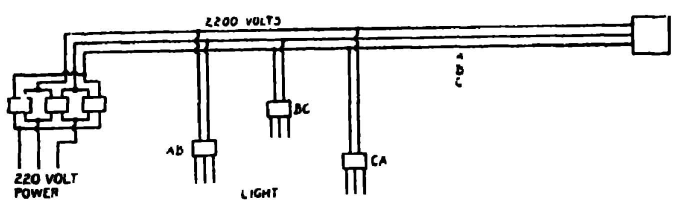


Fig. 9 Three-Phase Three-Wire Circuit

main. Small motors, up to about 5 hp., are generally supplied from a single-phase tap, while the larger motors, up to 30 or 40 hp., are supplied from two phases with the open delta connection.

Three-Phase Four-Wire System. A three-phase four-wire system, Fig. 10, is usually operated at 3800 volts between phase wires and 2200 volts between any phase wire and neutral. This gives the advantage of 3800-volt distribution in the feeder system and permits the supply of energy over a radius about twice as great as with 2200-volt systems, with the same regulation. Standard 2200-volt transformers and other accessories are used, and the lighting branches are single-phase. The unbalanced load is carried by the neutral wire, and with the use of line-drop compensators good pressure regulation is possible with any proportion of unbalanced load.

The four-wire distributing mains are carried only where there are motors or large loads to be served, and but three wires are

needed for installations of less than 30 to 40 hp., which may be served by two transformers connected in open delta. The wide range permissible has led to the adoption of this system in many of the larger cities of the United States. It is also well suited to the supply of suburban districts and rural communities, where double-voltage, 4400–7600 volts, may be used to supply a group of towns and villages, the pressure being regulated independently on each phase at the source of supply.

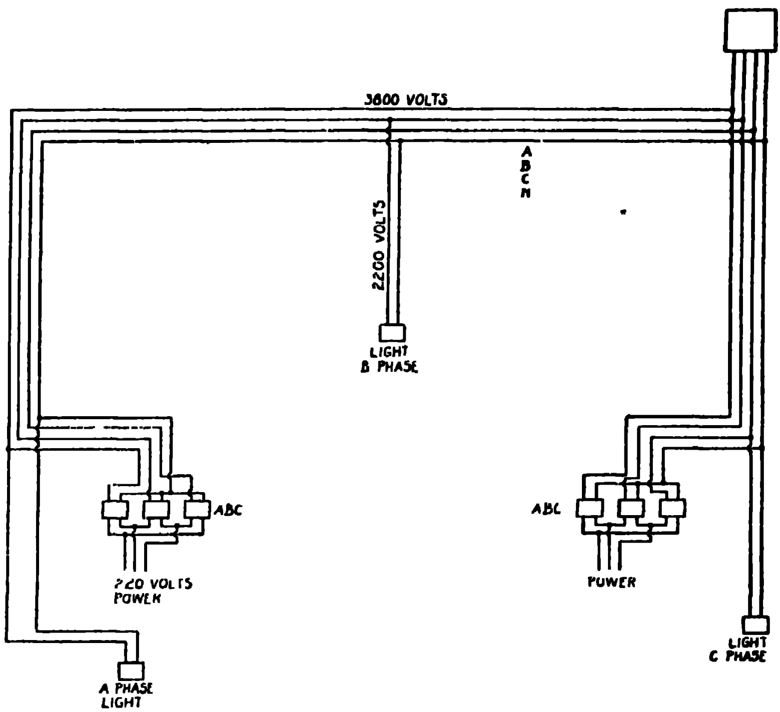


Fig. 10. Three-Phase Four-Wire Circuit

DISTRIBUTION IN CITIES

DIRECT-CURRENT EDISON SYSTEM

Extent of Use. Direct-current Edison systems are found in the central portions of the larger cities where the load per city block is very heavy and the feeders are only from 1500 to 2500 feet in length. Under these conditions the cost of installation per kilowatt is not much higher than the cost of a.c. feeders and mains covering distances of 2 to 3 miles from the point of supply,

since the saving made in the size of feeders at 2200 volts is largely absorbed by their greater length.

Feeder System. The Edison system is made up of feeders and mains as illustrated in Fig. 11. Feeders are usually made up of 750,000 to 2,000,000 CM cable, being two to three times as

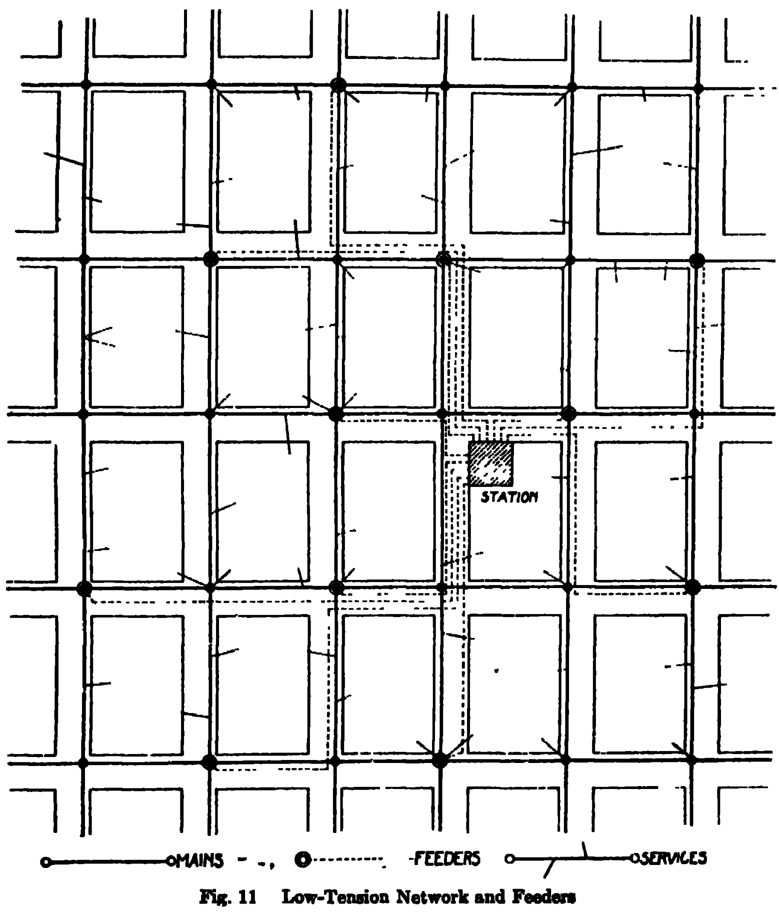


Fig. 11 Low-Tension Network and Feeders

large as the mains in the district they supply. The buildings are connected by taps from the mains called *services*, and the feeders are connected in at intersections. The feeder is usually run from the substation to its terminal point without being connected in at intermediate points. The longer feeders are supplied from a separate bus at higher pressure than the shorter feeders, thus maintaining an even distribution of pressure on the mains at the

feeder ends. In a large substation having several feeders of extra length a third bus is sometimes maintained. If there are only one or two extra long feeders, it is usual to provide for these by inserting a booster in series with them. This is a motor-driven generator which adds the required amount to the feeder pressure after it leaves the bus.

Method of Maintaining Constant Pressure. The pressure is maintained at the feeder as the load changes by observing a voltmeter in the substation which is attached to separate *pressure wires* brought back from the feeder end for this purpose. It is usual to select a feeder which represents the average condition at the feeder ends as a *standard* feeder. The pressure on each bus is then regulated so as to keep the pressure constant at the end of each of the standard feeders. It is not necessary to maintain separate busses at all hours of the day, but only during the period when the load is more than about 50 per cent of the usual maximum load.

In the case of large consumers, such as a department store or tall office building having a load of 150 kilowatts or more, it is usual to run a feeder direct to the consumer's premises, also giving him a service from the mains as a reserve supply. This service also ties the feeder into the general system and tends to steady the pressure at the feeder end.

Network of Mains. The mains, from which the buildings are connected, are connected into junction boxes at each point of intersection. Thus the energy is usually distributed in four directions from a feeder end. A service connected near the middle of a block may draw from the feeders at each end. Thus a 500,000 CM service may be supplied from a 350,000 CM main without overloading the main. The mains are interconnected through fused junction boxes. These fuses are usually copper strips of such size as to allow the main to carry any load up to twice its normal full load before blowing. This obviates trouble due to blowing of fuses at small overloads and yet cuts the main off at each end in case of a short-circuit within the block. Such a short-circuit does not blow the fuses in the junction box supplying the mains in other adjacent blocks, since the current is drawn from several directions and is not large enough to blow these fuses.

The network must be supported by adding feeders as the load increases. This is usually done by bringing them to intersections where no feeder is terminated; in districts where the load is very heavy it is sometimes necessary to bring two feeders to the same street corner.

Sizes of Mains. The calculation of sizes of mains for a network is an interesting problem which has received considerable study, but such calculations are of little value in American cities where growth is rapid and sizes which are correct in theory this year may be inadequate a few years later. It is therefore more practical to select a few standard sizes for mains such as 250,000 CM, 350,000 CM, 500,000 CM, and 1,000,000 CM and make all installations large enough to last for some years ahead.

Types of Construction. *Edison Tube.* The earlier d.c. systems were laid with Edison tube, and much of this is still in service after being twenty-five years in the ground. The tube is made up of iron pipe in which three bare copper rods are embedded in insulating compound and brought out at the ends through an insulating separator. These tubes are jointed up in 20-foot lengths, and services are taken by T couplings at the joints, Fig. 12. These tubes were laid near the curb on each side of the street where the load was heavy or in alleys where available.

Fireproof Conduit Systems. The system was discontinued after a time with the introduction of fireproof conduit systems into which lead-covered cables are drawn. This change was made because it was necessary to break out paving whenever a burnout occurred in a main, and with the growth of the system reinforcement cost more than the original installation. With cables drawn into conduit the street paving is not interfered with after the conduit is laid, since the cable if burned out or overloaded is readily withdrawn and replaced by other cable.

Storage-Battery Reserve. One of the principal advantages of continuous-current distribution is the possibility of having a storage-battery reserve. In order to be of the greatest value, the battery reserve should be distributed in a number of individual units located at central points in the system so that it can act as a reserve in case of the failure of the supply in any part of the system.

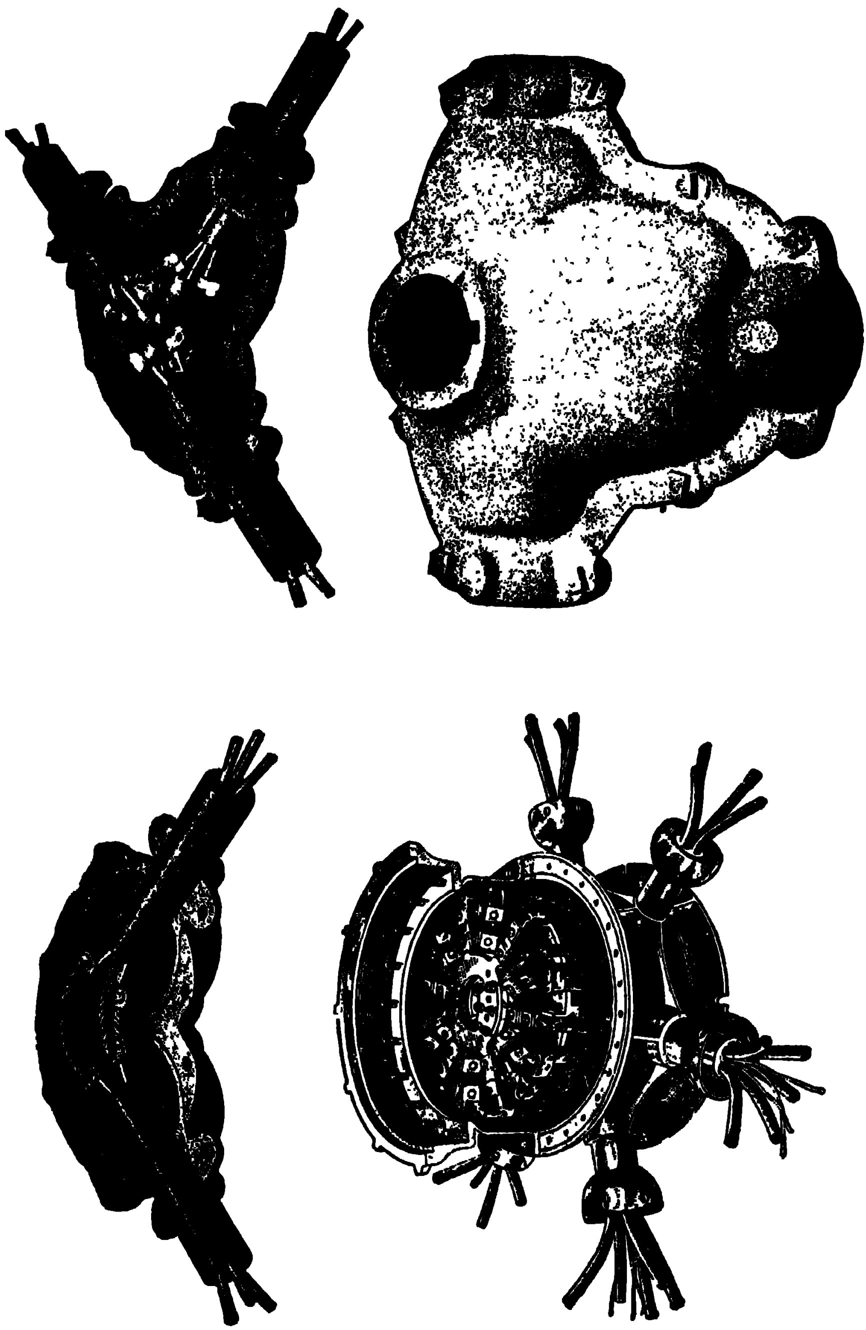


Fig. 12. Coupling Boxes Used in Edison Tube System

Battery Rooms. On account of the evolution of gases and the presence of acid vapor, it is necessary that the portion of the building occupied by the battery be provided with ample ventilating facilities and that all metal work be covered or painted as well as possible.

ALTERNATING-CURRENT SYSTEMS

Extent of Use. Alternating-current distribution is used for the majority of electrical distribution, because the lines can be operated at voltages around 2200, thus ensuring more economical

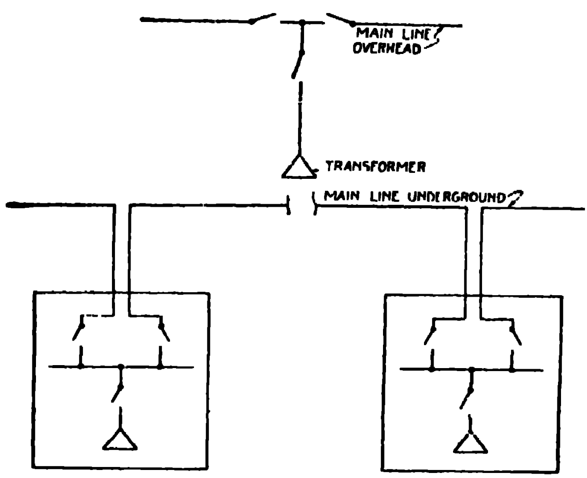


Fig 13. Emergency Connections, Bulk Supply Lines

operation and more satisfactory regulation of pressure. At 2200 volts the distributing mains are usually not larger than No. 6 wire, and the energy can be distributed over an area of 2 to 3 miles from the point of supply without difficulty.

Bulk Supply Systems. In the larger cities it is most economical to distribute the energy from the point where it is generated by high-voltage lines having a capacity of about five times as much as that of the ordinary size of distribution feeder. These lines constitute a bulk supply system consisting of three-phase transmission lines operated at pressures of approximately 13,000 volts. These lines supply energy to substations in quantities of 1000 to 5000 kilowatts each, and there it is transformed

to the distributing voltage. The larger manufacturing establishments using over 300 kilowatts are also supplied from these bulk supply lines by substations transforming the energy to a voltage suitable for distribution about the premises.

Emergency Facilities. Where bulk supply lines are carried overhead, it is usual to connect industrial concerns by tapping them through pole top disconnecting switches so arranged that the line can be sectionalized in case of trouble. With underground lines a loop is made into the premises and the sectionalizing switches are placed within the substation, where they are

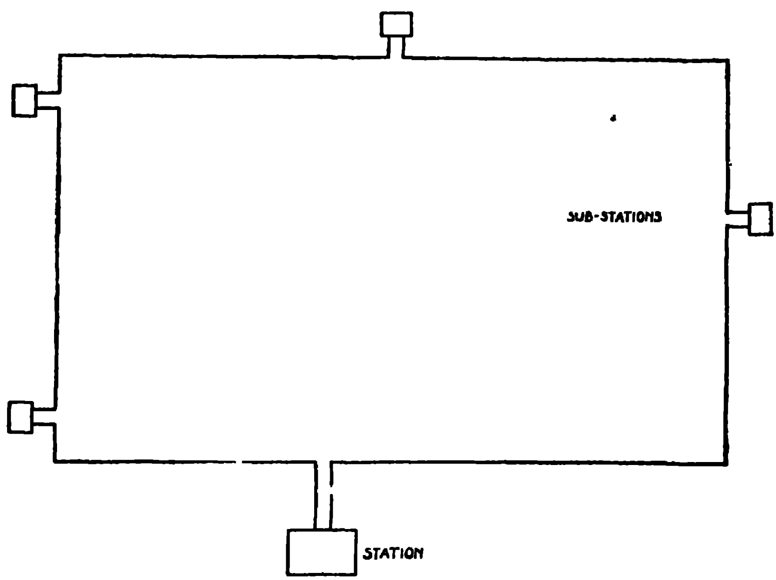


Fig. 11 Ring Distribution

provided with relays arranged to open the side of the loop on which trouble may develop. These connections are illustrated in Fig. 13.

Reserve Supply. The service to substations and manufacturing plants must not suffer an extended interruption and it is necessary to provide an adequate reserve supply. If only one substation is involved in a given direction from the power station, this is accomplished by providing one extra line as reserve. The reserve and regular lines should be carried by different routes if

possible to insure the reserve being available in case of trouble to the pole line or conduit system, as the case may be.

If the substation can be joined in by making a ring, this is usually the most economical way of providing reserve connections. Such a ring can often be so routed as to take bulk supply lines through districts where there are large plants to be served by them, thus reducing the expense for extending lines to reach such large users when occasion requires. Such a ring is shown in Fig. 14.

Size of Cables. Bulk supply lines are necessarily placed underground to a large extent. This involves the use of paper-insulated lead-sheathed cables, which are made up with the three conductors of the circuit under one sheath. With standard 3.5-inch ducts the largest size of cable which can be drawn into the duct is about 3-inch outside diameter, and this limits the maximum size of the conductor which can be used with a given thickness of insulation. At pressures of 6600 volts 400,000 CM sector-shaped conductors are the largest in use. At 13,000 volts about 350,000 CM is the maximum size. This fixes the maximum load which can be carried continuously on such cables at from 4500 to 6000 kilovolt amperes.

In the larger cities where certain substations distribute loads of 8000 to 15,000 kilowatts, several cables are required to supply each substation, and it is desirable to have cables of the maximum size.

Pressure Regulation. *Potential Regulators.* The distributing feeders should be equipped with potential regulators in order to provide proper distribution of pressure. Two types of potential regulators are in general use, one of which consists of a transformer with a switch in the secondary so arranged that pressure may be added to or subtracted from the bus pressure. In another type the secondary of a transformer is mounted on a movable core so arranged that more or less of the magnetic flux may be passed through the secondary winding and the pressure thus raised or lowered by inductive action. The latter is called the *induction regulator* and is preferable to the other type on account of the absence of sliding contacts, which are troublesome in operation.

Regulators may be controlled by hand, by motor drive from hand-operated switches, or by motor drive from automatically operated switches. The expense of automatic control is justified in important substations by the improved service given.

Line-Drop Compensators. The use of pressure wires to indicate the pressure at the end of a feeder is not necessary on a.c. feeders, since they can be regulated by the use of line-drop compensators. The length of a.c. feeders is usually so great that the cost of pressure wires is more than the cost of the compensator

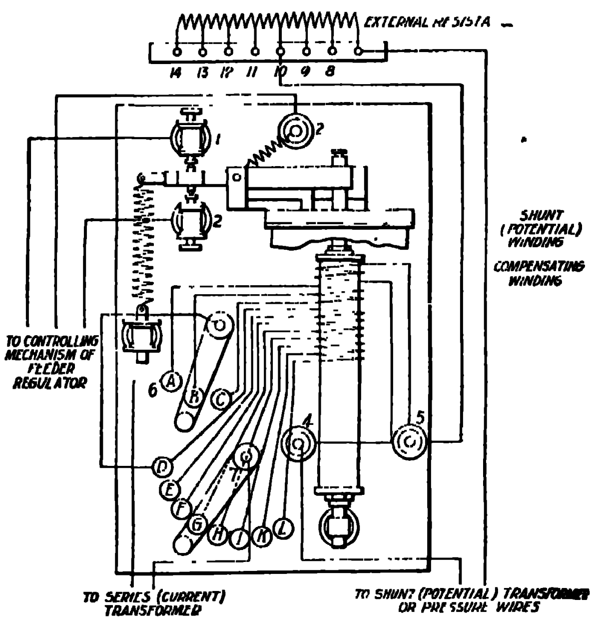


Fig 15. Contact-Making Voltmeter Connections

equipment. In principle, this equipment consists of a miniature circuit containing the same proportion of resistance and inductance as the feeder circuit which it regulates. The drop in this resistance and inductance is inserted in the voltmeter circuit in such a manner as to reduce the voltmeter reading by the amount of the feeder drop. The amount subtracted from the voltmeter reading by the line-drop compensator is directly proportional to the load carried by the circuit and to the power factor, so that when the line-drop compensator is once properly adjusted, the

voltmeter gives a correct indication of the pressure at the feeder end at all loads.

Automatic Regulation of Feeder Voltage. In connection with automatic regulation the General Electric Company has developed a device which serves as a combined line-drop compensator and relay. This device, known as a *contact-making voltmeter,* is shown in Fig. 15. It consists of a solenoid having windings which are tapped at various points and brought out to adjustable switches, as in the line-drop compensator. One winding produces a magnetic flux proportional to the pressure; another carries current in proportion to the load and opposes the flux due to the feeder pressure. This counter-magnetomotive force may be adjusted roughly by setting the proper switch on the points *A*, *B*, or *C*, and the finer adjustments are made by the points from *D* to *L*. The pivoted bar carries the contacts which control the supply of energy to the feeder regulator.

As the load increases, the plunger falls until the contact is made which raises the pressure on the feeder. This increases the flux due to the pressure, and the plunger rises sufficiently to stop the movement of the regulator until a further change in load or bus pressure occurs. This device gives very satisfactory results at all power factors from 75 to 100 per cent.

Feeders and Primary Mains. *Drop from Feeder End to Transformer.* The feeder is the unit of distribution at 2200 volts, or 2200–3800 volts if the circuit is three-phase four-wire. There should be a sufficient number of feeders to permit proper distribution of pressure over the mains to the transformers. This usually requires that the drop from the feeder end, or center of distribution, to the average transformer be not over 2 per cent. There are sometimes long extensions, however, where the conditions are such that the drop may be as much as 5 per cent or more. In such cases it is necessary to install a booster transformer until such time as the growth of the system will warrant extending the feeder.

Maximum Load on Feeder. In the more heavily loaded districts where the distances from feeder end to transformers are short the drop in the main is not the limiting factor. In such cases the number of feeders is more often determined by the

amount of load which it is desirable to have on a feeder in case of an emergency. For instance, in a system having a load of 2000 kilowatts it will be easier to transfer load from a feeder which is in trouble to the other feeders if there are four feeders carrying about 500 kilowatts each than if there are three feeders carrying 600 to 700 kilowatts each. Furthermore, as the load on the system increases from year to year, necessitating new feeders, it is necessary to shift the location of centers of distribution from place to place. This can be done much more readily if the load of the feeder is restricted to a current value which can be distributed from the center over No. 6 or No. 4 primary mains.

The points chosen for centers usually have primary mains radiating in three or four directions, and as the capacity of the main is about 50 amperes, this limits the current on a feeder to a value between 150 and 200 amperes. At 2200 volts this represents a load of about 700 kilovolt-amperes on a three-wire three-phase circuit or 1100 kilovolt-amperes on a four-wire feeder. These values are the maximum values permitted before providing an additional feeder for relief. In practice there are always a part of the feeders carrying loads smaller than these, so that the average load on a group may not exceed 66 to 75 per cent of these maxima.

Size of Conductor. The size of conductor used for feeders is therefore usually No. 0 to No. 0000. At an average maximum-load current of 125 to 200 amperes these sizes are also economical when fixed charges and the value of energy loss on the feeder are taken into account. Where lines are overhead, primary mains are usually made not less than No. 6 or No. 4 as a matter of mechanical strength. In central business districts where transformers are large and the mains are short No. 2 or No. 0 wire is often used.

Emergency Facilities. The primary main system cannot be interconnected through fused junction boxes to permit parallel operation as is done with a low-tension network. The working pressure being so much higher and the current values correspondingly lower than in a low-tension system, it is not possible to have a fuse cut out a section of main which is in trouble without

at the same time blowing fuses supplying other sections of main and thus spreading the trouble. It has therefore been found necessary to eliminate fuses from the primary main system except for the line transformers. Thus the mains from the center of distribution to the transformers are arranged according to the "tree" system for the most part, each branch coming to a dead end and having only one feeding point.

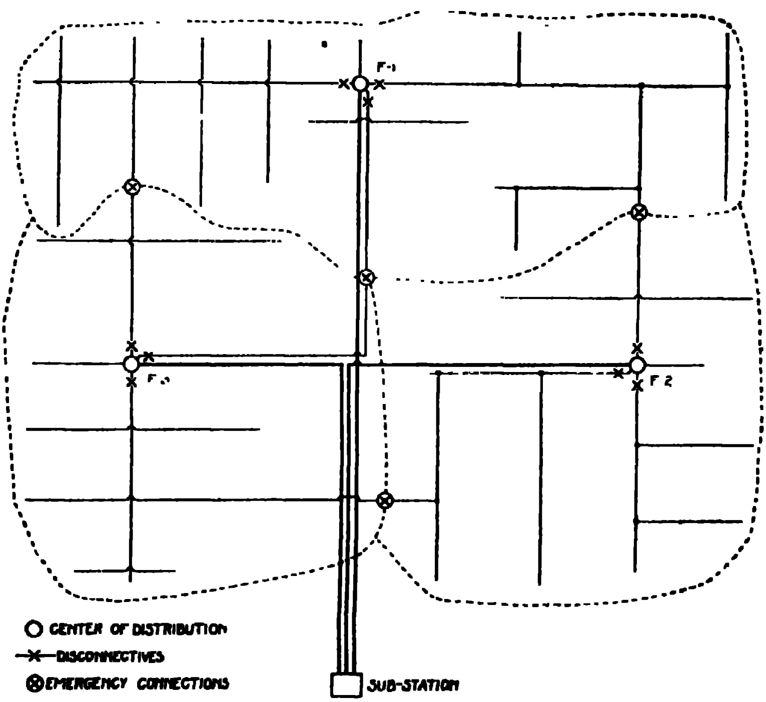


Fig 16. Arrangement of Emergency Disconnections

Where important service is dependent upon these mains, as in theaters, stores, and factories, it is necessary that the mains be so arranged and equipped as to permit the ready transfer of important transformer installations to a reserve source of supply in an emergency. This is accomplished by arranging the primary mains of feeders which supply adjacent territory so that the branches of one feeder will terminate at the same point as branches of the adjacent feeders; these junctions are known as *emergency* points. In case of trouble the load can be transferred

as soon as the "trouble-man" can locate the main which is in trouble and close the switch at one of the emergency points, thus connecting the circuits.

Each important branch from the feeder is provided with a disconnective pothead or other device at the point of supply so that this branch can be cut off, if in trouble, and service resumed on the remainder of the feeder. An example of this arrangement appears in Fig. 16.

Economic Size of Conductors. *Calculation of.* The most economic size of conductor for a circuit is that *for which the sum of the value of the energy lost and the fixed charges on its first cost is a minimum.* The fixed charges should include those on that portion of the power station capacity which is absorbed in supplying the loss on the circuit at the time of the maximum load on the plant.

The energy losses increase as the size and the cost of conductors is decreased for a given load, and vice versa. The plant capacity absorbed by the loss follows the same law. The value of the energy loss depends on the cost of production per kilowatt hour. These items vary in different systems and the calculation is necessarily quite elaborate and complicated. However, it is found that under the average conditions in American cities the best size for a given load may range from 0.6 to 1 ampere per 1000 circular mils without greatly changing the total cost.

Current-Carrying Capacity or Voltage Drop as Basis of Selection. The selection of conductors on the basis of current-carrying capacity usually results in current densities of about 0.8 to 1.5 amperes per 1000 circular mils in the sizes used for distributing feeders, and where drop is the limiting factor, there may be but 0.5 ampere per 1000 circular mils. Hence the selection of conductors on the basis of carrying capacity or voltage drop gives results which are not far from the best economic sizes.

PROTECTIVE EQUIPMENT

Fuses. The use of fuses for protection in low-tension lighting systems is universal because of the low cost of fuses as compared with circuit-breakers. In power systems where the circuits are opened frequently the circuit-breaker is found to be preferable.

TABLE VIII

Fusing Currents of Copper and Aluminum Wires

	Size of Wire, A.W.G.						
	8	10	12	14	16	18	20
$\sqrt{d^3}$	0.046	0.0325	0.229	0.0162	0.0114	0.0081	0.0057
Fusing Current of Copper (amperes)	472	334	235	166	117	83	58
Fusing Current of Aluminum (amperes)	349	245	174	123	86	61	43

The law of the operation of fuses was developed by Preece in 1888. It may be stated in the form

$$\text{Current} = a\sqrt{d^3}$$

d being the diameter of the wire expressed in inches. The value of the constant *a* varies with the kind of metal used. For copper it is 10,244; for aluminum 7585; for lead 1379; for tin 1642; and for iron 3148. The fusing currents of copper and aluminum wires are given in Table VIII.

The protection of a distribution system is necessarily a compromise between conflicting conditions. The location of fuses should be such that the area affected by the operation of a fuse is small. On the other hand a fuse is liable to operate when it should not, owing to corrosion or poor contacts; therefore fuses should not be multiplied unnecessarily.

Overhead Lines. In overhead a.c. lines experience has demonstrated that very few fuses should be used. The principal branches should be provided with disconnectives which can be readily used in locating trouble, and the use of fuses should be limited to branches where there is a continuous hazard, such as trees.

Underground Low-Tension Networks. In underground low-tension networks the sectionalizing (with fuses) must be done with great thoroughness owing to the length of time required to make repairs and the importance of the service. Trouble on a distributing main should be limited to the block in which it occurs and, if lines are carried on both sides of the street, to one side

of the street. It is usual to place fuses at all junction points in networks. Sheet-copper fuses are generally used for this purpose. The section of the copper where fusion takes place is designed to fuse at about twice its normal load.

The feeders are fused at the point where they connect into the network to protect the network against trouble on the feeder. It is not usual to provide fuses on low-tension feeders at the station, as the operator can open the switch in case it is necessary.

Transformers. When the network is fed by subway transformers, an additional link is introduced in the system. Both sides of the transformer should be connected to the system through junction boxes so that the unit can be easily cut off from the system if it burns out.

Line transformers should be provided with primary fuses of such size that they will not blow unnecessarily. The porcelain type of fuse furnished with the transformer has proved very satisfactory for transformers up to 20 kilowatts. Aluminum is used as the fuse metal up to 15 or 20 amperes at 2200 volts. Above 25 amperes various types of fuse have been tried, but the amount of energy concentrated at the arc makes the problem difficult. The cartridge fuse is effective to 50 amperes but it is difficult to keep it dry enough to prevent the filler from absorbing moisture when used out of doors.

Circuit-Breakers. Oil circuit-breakers are preferable as a means of protection where automatic cutouts operate at frequent intervals and also for circuits operating at high voltages and controlling loads of 100 kilowatts and upward. In general, the circuit-breaker is expensive in first cost but inexpensive in operation, while the use of fuses involves a considerable maintenance charge but small first cost.

Lightning Protection. Overhead distributing lines are susceptible to the effects of lightning. A discharge among the clouds causes an abrupt discharge of potential on the wires, which must be given an opportunity to escape to earth without injuring the insulation of the apparatus.

The function of lightning arresters is to protect apparatus by passing the discharge of lightning to ground without permitting the arc thus established to be maintained. This may be accom-

plished on potentials up to 600 volts by a short gap of non-arcing metal. At 2200 volts or higher several gaps in series are necessary with a resistance to limit the current. Since each wire of the circuit is affected, discharge gaps must be provided between each wire and ground.

In systems having one side grounded every discharge is likely to be followed by the generator current, as there is a fixed difference of potential between the circuit and earth. Arresters on grounded systems must therefore meet more severe requirements than those on ungrounded systems.

Types of Arresters. The wide range in severity of lightning flashes makes it well-nigh impossible to design an arrester which will protect apparatus and yet withstand the effects of a direct stroke at any point near-by. The arresters described in the

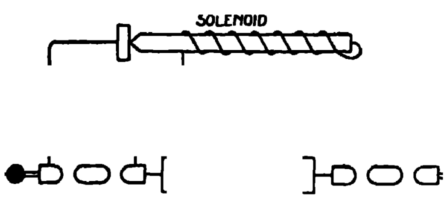


Fig. 17. Solenoid Type Lightning Arrester

succeeding paragraphs include the leading commercial types which have been used in distribution work.

The Garton-Daniels arrester, Fig. 17, consists of air gaps and resistances, with a solenoid so arranged that the plunger is raised by the passage of the generator current, thus placing additional gaps in series and rapidly diminishing or stopping the flow of energy. The lightning discharge passes across the shunted gaps to ground, owing to the inductance of the solenoid.

A multi-gap arrester, or modification of the spark gap and resistance type of arrester, has been employed quite extensively. This is illustrated in Fig. 18 as made for 2200 volts and consists of three paths of discharge: one which has a high resistance; another which has a resistance of about 300 ohms; and a third which consists of thirteen or fourteen gaps without resistance.

The impedance of the unit is such that discharges of very high frequency pass over the thirteen or fourteen gaps, while those of

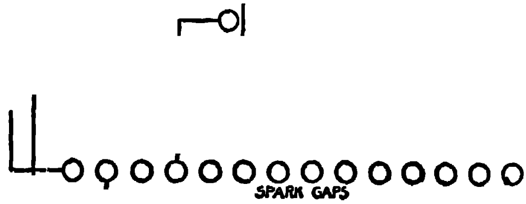


Fig 18. Multi-Path Lightning Arrester

lower frequency pass over the smaller number of gaps through one of the resistances.

The compression type of arrester, Fig. 19, consists of a series resistance with air gaps assembled inside of a porcelain tube, the top of which is capped and sealed. The air gaps are surrounded by a grounded strip of iron outside the tube, which acts as a means of equalizing the potential gradient. The discharge of the arrester expands the air and compresses it since the tube is sealed; hence the name compression type. This arrester, having but one path to ground, is of limited capacity.

Location of Arresters. All the above-described types of arresters are in general use on distributing systems in America,

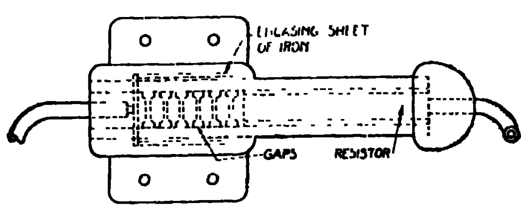


Fig. 19. Compression Type Lightning Arrester

and each gives reasonably good protection to apparatus when placed in its immediate vicinity. Experience has demonstrated

that lightning discharges do not travel any great distance along a line. The arrester must therefore be *as near the apparatus as practicable* and preferably on the same pole. Complete protection of distributing transformers would require that an arrester be placed on every transformer pole. The experience of large companies, however, has been that the cost of the damage to apparatus from lightning is not as large as the fixed charges on the arrester equipment when complete protection is provided.

SECONDARY DISTRIBUTION

Systems Used. The secondary mains of an a.c. system serve users in a local area, while the primary mains supply larger areas.

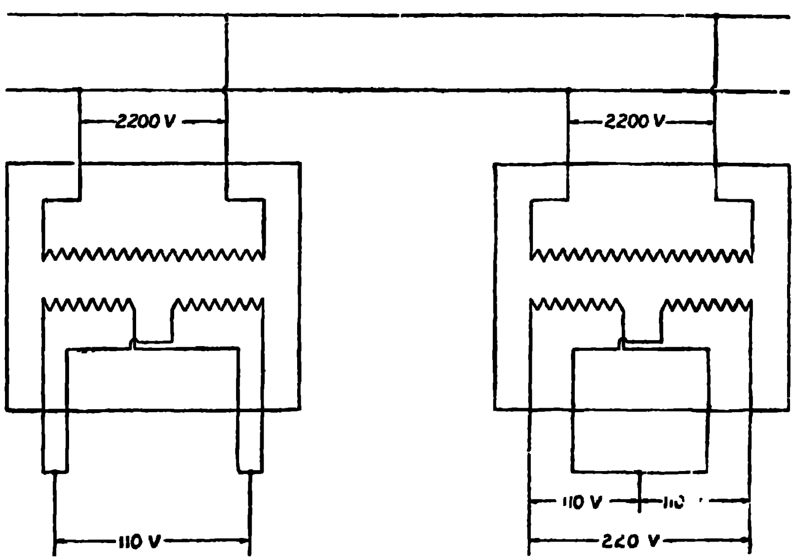


Fig. 20. Connections of Standard Line Transformers

The system of secondary distribution most used is the single-phase three-wire Edison system at approximately 110–220 volts for lighting and small motor service, and 220-volt two-phase or three-phase for general motor service; 440 volts and 550 volts are also used to some extent for power systems in industrial plants. For the supply of mixed service of lighting and motors from a secondary network the four-wire, three-phase system at 115–200 volts or 120–208 volts, approximately, is sometimes used.

The connections for single-phase two- and three-wire appear in Fig. 20, and those for three-phase power in Fig. 21.

The voltage of general distribution systems must be low enough to be adapted to incandescent lamps, fans, heating devices, and other small accessories, which are preferably made for a voltage around 110. Motor voltages are higher in order to secure economy of conductor investment.

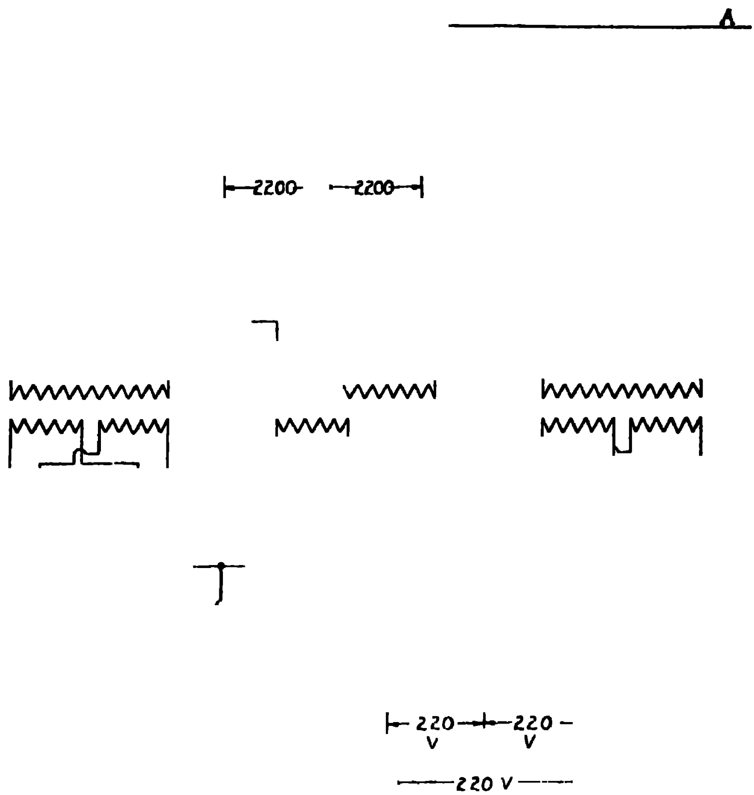


Fig. 21 Three-Phase Delta Connections

Line transformers are usually wound with a ratio of 2200 to 110–220 volts so that they may supply a three-wire secondary main. The voltage for motors of 1 hp. and larger being 220, the same stock of transformers may be used for light and for power service.

Where light and power are served from a three-phase secondary, the light is put on one phase if it is small as compared

with the power load, as in Fig. 22. Where the lighting is the principal load, as in a retail store district, the light and power are sometimes served from a Y-connected secondary main, as shown in Fig. 23. This system is harder to keep balanced than a three-wire Edison system and involves a four-wire service for the larger consumers and for those having light and three-phase power. It is therefore not used very generally.

Separate Transformers for Large Motor Loads. The design of secondary systems is subject to restrictions when inductive loads, such as arc lamps and motors, must be served along with incandescent lighting. The heavy starting current required by induction motors may momentarily overload the transformer and the secondary main. This causes a flickering of incandescent

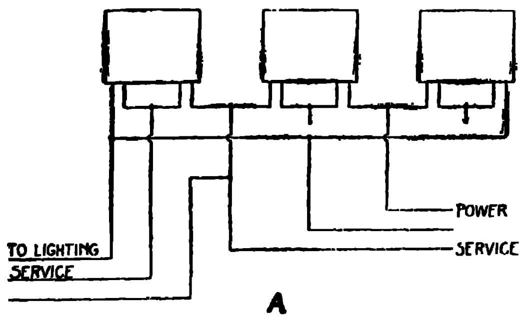


Fig. 22. Connections for Light and Power Service from Three-Phase Secondary, Light Load Relatively Small

lamps served in the vicinity. It is necessary, therefore, to install separate transformers for installations of motors if the best regulation is required for incandescent lighting. Motors larger than 10 hp. cannot usually be supplied from a lighting network without interfering with the service.

Selection of Transformer Sizes. The selection of the size of transformers for various classes of consumers is important since excess capacity involves idle investment and unnecessary core losses. Where a number of consumers are served by one transformer, the various maximum demands do not occur simultaneously and the resultant maximum demand is less than the sum of the individual demands.

Demand Factors. Certain ratios of maximum demand to connected load may be established by a series of measurements

for the various classes of consumers for which it is necessary to select transformers. These ratios, or demand factors, may then be applied with reasonable accuracy to the transformers for new consumers.

In store lighting the maximum demand for window lighting, signs, and other display lighting is from 90 to 100 per cent of the connected load. The demand for interior store lighting is from 50 to 70 per cent.

In residence lighting where the connected load is fifty lamps or less the average demand factor of a group of residences is

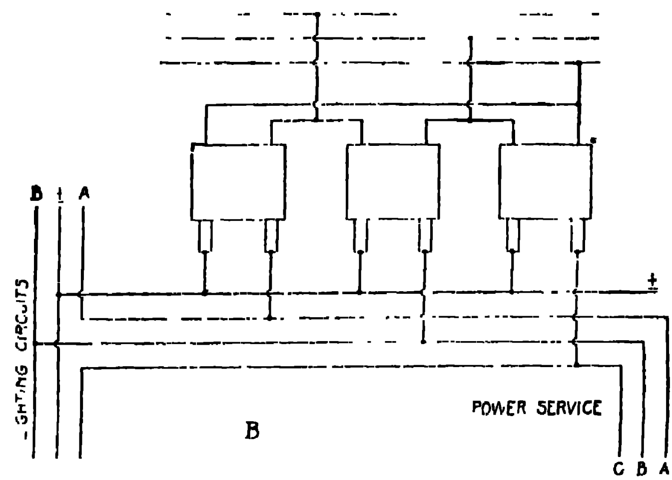


Fig 23 Connections for Light and P[illegible] from Three-Phas[illegible] Secondary, Light Load [illegible]arge

from 15 to 20 per cent of the connected load; small residences and apartments having connected loads of twenty lamps or less average about 20 per cent of the connected load.

In theater lighting the border lamps and the foot lamps, of several colors, are not used simultaneously; and the stage and the auditorium are not lighted simultaneously except for a very few minutes at a time. In a small theater the demand factor may be from 70 to 85 per cent, while in a large theater it frequently runs as low as 50 per cent.

In general, a higher ratio must be used where there are but few consumers served from one transformer than where there are more, as the occasional maximum demands of individual consumers are proportionately much larger.

The selection of transformers for motor loads is more difficult, as the maximum load may vary greatly from day to day or from month to month. Elevator and crane motors require transformers having 100 to 125 per cent of the rated motor capacity, unless there are several motors supplied by one unit; this is necessary in order to hold up the pressure in starting.

For general power service the maximum demand is approximately two-thirds of the connected load for installations of several motors aggregating not over 30 hp. Over 30 hp. it is usually from 45 to 60 per cent of the connected load.

Stages in Development of Secondary Systems. In the districts where consumers are very much scattered there are often transformers supplying only one or two consumers with perhaps only two or three spans of secondary main. In other districts there are enough consumers to have a transformer in each block, but the systems are too small to join together in parallel. In the more congested districts the secondary mains are continuous and are connected in parallel so that the adjacent transformers may assist each other in carrying heavy loads which may come on at certain times at various points on the system. As a city grows the secondary system is changing from one of these stages to another.

In scattered districts, when a new consumer is to be added, the problem usually is whether an additional transformer shall be installed or an existing secondary extended, or, if a secondary is available, whether an existing transformer shall be replaced by a larger one. If no secondary is available, the cost of extending the nearest one should be compared with the cost of installing a transformer. It is usually more economical to extend the secondary than to install a new transformer if the cost of the extension does not greatly exceed the cost of the transformer. In some cases it is necessary to increase the transformer capacity as well as to extend the secondary and this should be taken into account in making comparative estimates.

Interconnected System. Where the system is of such size as to be interconnected, this is usually done through sectionalizing fuses located at a point about midway between transformers, so that in case a transformer is cut out by the operation of its

fuses, the transfer of the load to the adjacent transformers will blow the sectionalizing fuses rather than the fuses of an adjacent transformer. If the fuses of adjacent transformers were blown, this would further overload the remainder of the interconnected system and put the entire system out of service. This possibility is the chief disadvantage of interconnected operation, and the location and the size of the sectionalizing fuses must be carefully selected so that these fuses will operate in an emergency before the fuses of adjacent transformers operate.

Where the arrangement of lines is such that the secondary mains are chiefly in straight lines without intersecting mains, there is little gained by the operation of the secondary mains of adjacent transformers in parallel.

The spacing of transformers is often fixed by the arrangement of street intersections, these naturally forming the points of location for transformers, from which they may feed mains in four directions. This usually results in a spacing of from 450 to 600 feet, and this arrangement is fortunately consistent with the use of economic sizes of conductor for various loads.

For a given spacing the size of the conductor should be such that lighting consumers midway between transformers receive pressure not more than 2 per cent below that at the transformer terminals. For power service it is permissible to have a secondary drop of 4 to 5 per cent.

It is desirable, however, in constructing lines where there is likely to be growth, to put in conductors of greater size than is immediately required as it is expensive to replace a secondary main when there are a multiplicity of service taps connected to it and this expense may easily offset any saving made in interest charges by deferring the investment in copper a few years.

Grounding. For the protection against high voltages of those using the service in buildings it is desirable that secondary mains be permanently grounded. This is done by connecting the neutral wire to water pipes or to a galvanized pipe driven into the ground about 8 feet at the base of a pole. It is desirable to have two or more grounds at different points. Water-pipe grounds are usually more dependable than driven pipes. Grounds should be connected at the points indicated in Fig. 24.

Transformer Connections. The connections of standard line transformers are shown in Fig. 20. These transformers are usually made with two secondary coils, which permits their use for 110 volts to supply lighting on the two-wire system or for lighting

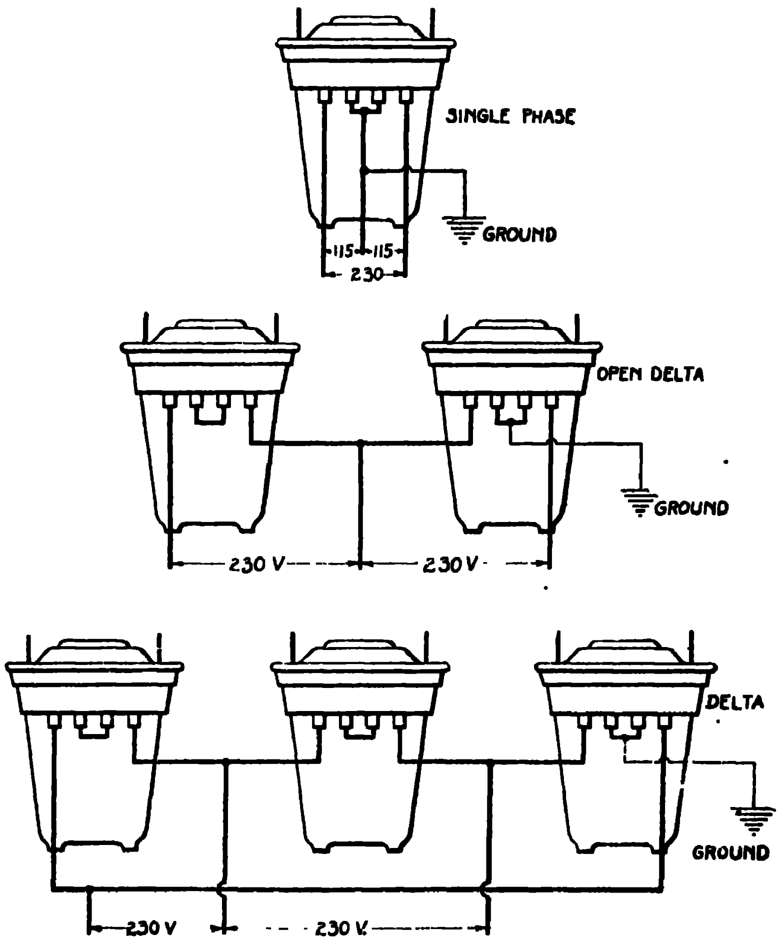


Fig. 21 Diagram of Secondary Ground Connections

or power on the three-wire Edison system at 110–220 volts at a ratio of transformation of 10 to 1. Some systems operating at approximately 2080 volts use a standard transformer having windings for 2080 volts to 115–230 volts, making a ratio of approximately 9 to 1.

The connection for three-phase three-wire is shown in Fig. 21 and is familiarly known as the *delta* connection. The four-wire connection in Fig. 23 is produced by connecting all right-hand terminals to the phase wires and all left-hand terminals to the neutral, or vice versa. This connection is called the Y connection.

In Y-connected four-wire distribution systems the pressure is operated at about 2200 volts between the neutral and each of the three-phase wires, giving approximately 3800 volts between the phase wires. Hence in order to use standard 2200-volt distributing transformers for three-phase power the transformers are Y connected on the primary side. The neutral conductor is usually not connected to a Y-connected power installation of three transformers.

The secondary connections for transformers with delta- or Y-connected primary may be made for delta three-wire operation or for Y operation with either three or four wires.

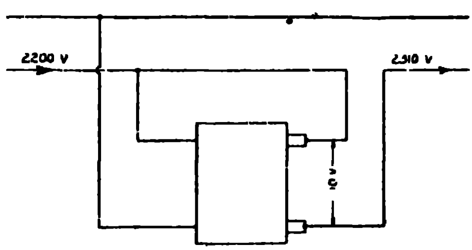


Fig 25. Connections for Booster Transformer

Booster Transformers. *Single-Phase System.* When it is necessary to raise pressure when line drop is excessive, this may be accomplished in a single-phase system in steps of 5 or 10 per cent by a standard 110–220 volt transformer so connected that the secondary is in series with the primary main line. This raises the primary pressure by the amount of the secondary voltage, thus boosting the pressure of the circuit, as shown in Fig. 25, by 110 volts, or 5 per cent. This increase in pressure is independent of the load carried by the circuit, and therefore the pressure is maintained at a point about 5 per cent above normal during the hours when the load is small.

It is desirable to place boosters as near the source of supply as possible, since the booster adds to the current drawn by the branch of the circuit in which it is connected.

The transformer used as a booster must have a capacity of at least 5 per cent of the maximum load on the main line, and if it is to boost 10 per cent, it must be able to carry 10 per cent of the load, etc.

With the secondary reversed the transformer becomes a choke, depressing the line pressure instead of raising it. The connection of the secondary for booster or choke must usually be determined by trial for any given type of transformer.

Polyphase Systems. The use of boosters in a delta-connected three-phase system is not so simple as is the single-phase application. The insertion of a booster on one phase affects the pressure on two phases. The effect of inserting a booster on each phase is shown in Fig. 26 in the dotted triangle. A booster on each phase connected for 110 volts adds 7.5 per cent to the pressure instead of 5 per cent.

Three boosters are required to keep conditions in balance in a three-phase three-wire circuit. In a Y-connected three-phase four-wire system the boosters may be connected in such a way that the pressure is controlled in each phase independently of the others. The booster is put in series with the phase wire, and the primary is connected from the same phase to the neutral.

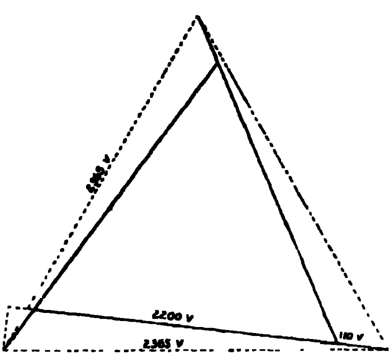


Fig. 26. Effect of Boosters in Three-Phase Three-Wire Circuit

Booster schemes should, in general, be regarded as tentative remedies rather than permanent schemes of operation. They should be eliminated as soon as the density of the load justifies a sufficient number of feeders to make their use no longer necessary.

Autotransformers. The introduction of incandescent lamps having characteristics which render them most durable at the lower voltages has greatly increased the field of application of the autotransformer. It is desirable in plants using 220-volt and 440-volt systems to have 110-volt circuits available for lighting.

The connections in Fig. 27 are those for two-wire 110-volt distribution on a 220-volt system with an autotransformer, the load being assumed to be 20 amperes. The distribution of current in the winding is indicated, from which it is evident that the capacity of the transformer is 50 per cent of the lighting load.

When the lighting is distributed on a three-wire 110–220 volt system, the transformer carries only the unbalance of current in the two sides of the system, as shown in the three-wire circuit in

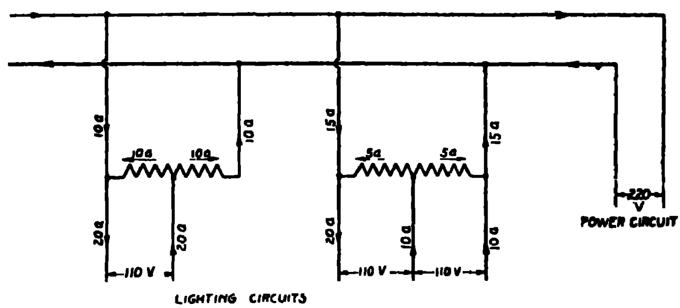


Fig. 27 Connections for Autotransformer

Fig. 27. In many cases the capacity need be only 25 per cent of the lighting load.

The lighting distribution in a 440-volt system is preferably accomplished by a standard transformer stepping from 440 volts to the three-wire 110-220-volt system. This requires transformers of capacity equal to the load and is desirable in order to prevent the lighting circuits being raised to 440 volts from ground.

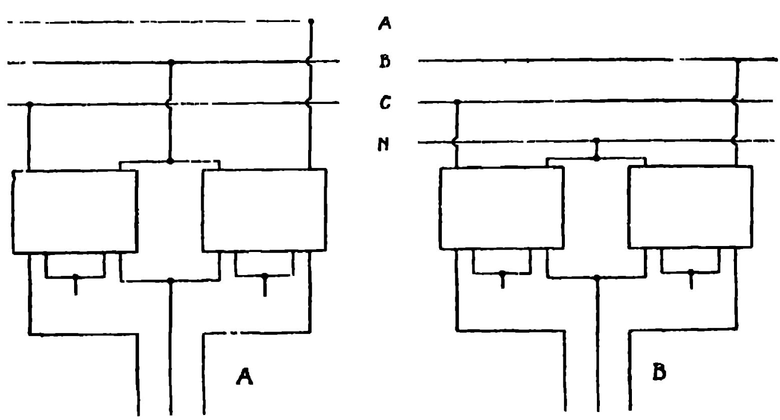


Fig 28 Connections for Three-Phase Service, Open Delta Secondary

Three-Phase from Two Transformers. Two connections are possible for the purpose of securing three-phase from two trans-

formers—one known as the *open delta* and the other as the T connection. The open delta connection for a three-wire system is shown at *A* in Fig. 28. This is merely an ordinary delta connection with one transformer left out. A simple rule by which this connection may be kept in mind is that *the middle wire of the line goes to the middle point between the transformer on both primary and secondary.* In order to reverse the rotation, the two outside wires must be interchanged on the primary or two of the three crossed on the secondary side. At *B* in Fig. 28 is shown the open delta connection supplied from a three-phase four-wire system. In this case the primary is connected to two of the phase wires and the neutral wire. To reverse rotation on the primary side, the phase wires should be interchanged.

With the open delta connection the current in the coils is 15.4 per cent more than it is with three transformers. That is, if three 5-kilowatt transformers are fully loaded by a given installation, they may be replaced by an open delta set of two 7½-kilowatt transformers, but the coils of the 7½-kilowatt units will be overloaded 15.4 per cent at full load of 15 kilovolt-amperes.

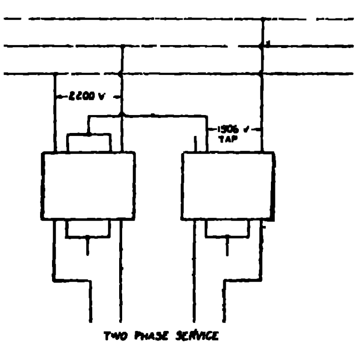


Fig. 29. Two-Phase Service from Three-Phase Mains

Two-Phase Three-Phase Transformation. The T connection may be used in transforming from three-phase to two-phase, or vice versa, as shown in Fig. 29. This is also called the Scott connection. It will be noted that one transformer must have a tap brought out so as to make the ratio of transformation on that unit from 1906 to 220 instead of 2200 to 220 as in the other unit. Standard lighting transformers are not usually equipped with 86.6 per cent taps.

It is impossible to derive 440-volt three-phase supply from a two-phase supply except with 440-volt transformers since transformers will not operate in series on the T-connected side of such a combination.

LINE CONSTRUCTION

OVERHEAD CONSTRUCTION

Woods Used for Poles. The usual form of overhead construction in American practice consists of wooden poles with the wires carried on crossarms. The woods which are best suited for pole work in America are the Michigan white cedar, western cedar, chestnut, and pine. Other woods are used, but to a limited extent.

Michigan cedar grows with a natural taper of about 1 inch in diameter to every 5 or 6 feet of length, except near the butt of the pole, where it flares out somewhat larger, making a very substantial and rigid pole.

Chestnut poles are found in the New England states and in the Appalachian range as far south as North Carolina. Chestnut is considerably heavier than cedar and is more likely to have knots which affect its appearance unfavorably. The sapwood is thinner and harder than that of cedar, and it is therefore somewhat less adaptable to the use of spurs in doing line work.

Western cedar is found chiefly in Idaho and Washington and has less taper than Michigan cedar, about 1 inch for each 9 feet of length.

Height of Poles. The height of poles selected for distribution purposes is governed by the requirements of clearance over local obstructions and by the number of crossarms to be carried on the poles. Clearance over trees is especially troublesome in residence sections where trimming is not permitted.

In general, it is not desirable to use poles less than 30 feet long where primary lines are carried, and in built-up sections a minimum size of 35 feet is preferable. Where joint construction with another company is used, it is customary to use no poles smaller than 35 feet.

The use of high poles is to be avoided wherever possible, in view of the cost of installation, the increased danger of failure in storms, and the difficulty of handling transformers and service connections.

Location of Poles. Poles should be placed close enough to keep the sag within safe limits and to provide a sufficient number

of points at which service drops may be taken off. The spans near self-supported corner poles should be about 75 feet if possible in order to relieve the strain on the corner poles. The poles should be placed opposite lot lines as far as practicable to avoid interference with the rights of abutting property owners. These requirements are usually met by span lengths of 100 to 125 feet.

Protection of Poles. The appearance of poles is usually of such importance that it is considered good policy to remove knots and give the poles two coats of paint. All poles which are likely to be climbed frequently, such as transformer poles and poles carrying fuse boxes, should be provided with pole steps. Poles which stand at corners where they are subject to abrasion by the hubs of passing vehicles should be protected from injury by the attachment of hub guards. The guard usually consists of a piece of plate iron bent to the approximate curvature of a pole and secured by suitable spikes.

Gains. The pole should be cut for the reception of the cross-arms before it is erected. These incisions, called gains, should be about ½ inch deep and of the necessary width to receive the arm. The distance between centers must be sufficient to allow a safe working space for linemen; the space usually allowed is 24 inches.

Pole Setting. Experience has shown that the following practice is conservative for setting poles in a straight line:

Size Pole (ft.)	30	35	40	45	50	55	60	70
Depth (ft.)	5	5.5	6	6.5	6.5	7	7	7.5

Corner poles should be set about 6 inches deeper than the figures given in the tabulation. The character of the soil and the diameter of the butt of the pole affect these figures in some cases. In rocky soil where bowlders may be tamped about the pole it need not be set so deep. Where swampy soil is encountered, the sinking of the pole may be accomplished by the use of a sand barrel. This consists of a sheet-iron cylinder about 30 inches in diameter and 3 feet long which is separable into two parts lengthwise.

In case the earth filling does not give sufficient stability, this may often be obtained by the use of concrete filling from 6 to 10 inches thick at the base of the pole and at the ground line. This has the effect of increasing the bearing surface of the pole and will prevent pulling out of line.

At corners, bends, and dead ends which cannot be properly guyed the pole carrying the strain must be self-sustained by the use of concrete or by timbers secured to the pole. Poles having top diameters of 8 to 10 inches should be used for this class of work.

Guying. At all points where the direction of a line changes, the tension of the wire should be supported by guying equipment, if possible. Guy wires are secured in various ways, depending upon the space available. When the guy wire can be brought down to the ground, the guy cable may be secured to an anchor. The location of poles is often such that guys cannot be run

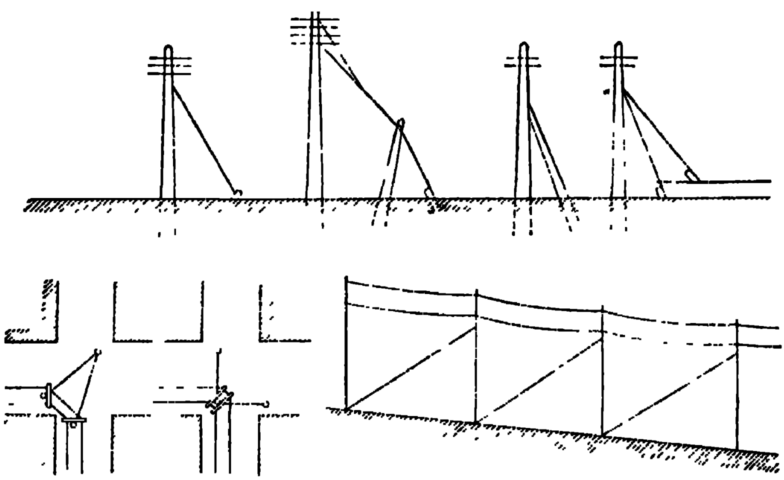


Fig. 30 Methods of Guying Poles

directly to anchors without interfering with traffic. Such guys must be run to a stub and attached at such a height as to permit free passage underneath. Guys over roadways should clear the crown of the road about 20 feet, and those over pathways should clear 12 feet. The various forms of guy attachments are illustrated in Fig. 30.

Where side-arm construction is used, it is necessary to support the crossarms as well as the pole at corners and ends by means of guys attached to eyebolts in the arms.

Guy Cables. Steel wire or cable should always be galvanized, since plain steel wire is subject to rapid corrosion. It is very difficult to bend steel wire in sizes above No. 8 B.W.G. with-

out impairing its strength. It is therefore generally used in the stranded forms for guying purposes.

Two sizes of stranded cable are commonly used for guying work, namely: ¼ inch, having an ultimate tensile strength of 2300 pounds; and ⅜ inch, having a strength of 5000 pounds. The 2300-pound wire is used for the support of lines having one crossarm only and for guying single arms in side-arm construction.

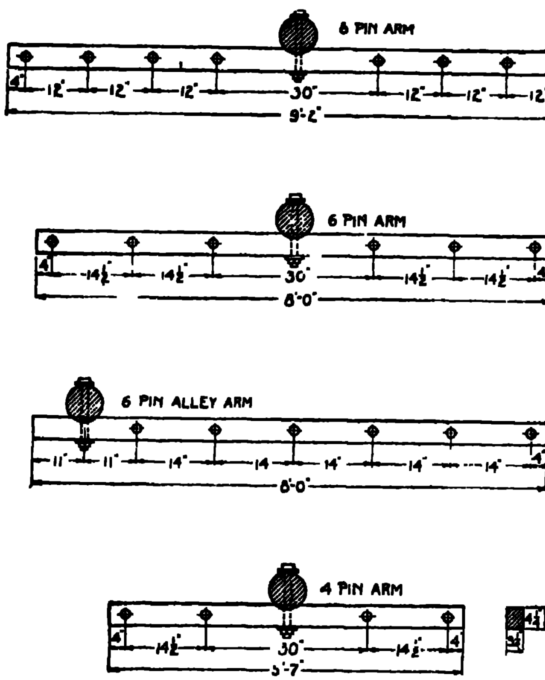


Fig. 31 Dimensions of Crossarms

Larger lines and heavier strains are commonly carried by the 5000-pound size.

Strain Insulators. The proximity of guy cables to primary wires affords opportunity for leakage and makes them subject to crosses with live conductors. It is therefore important that guy cables be equipped with strain insulators for the protection of the public and of linemen. The strain insulators are put in about 6 feet from each end.

Crossarms. In the selection of wood for crossarms longleaf Southern pine and Douglas fir are the best woods because of their

straight grain, high tensile strength, and durability. The grain should be straight, and there should be no knots over ¾ inch in diameter.

Experience indicates that a cross-section 3¼ inches wide by 4¼ inches high is ample for the average requirements of distributing lines.

Pin Spacings. Under the usual working conditions it is not safe to use pin spacings narrower than 12 inches for primary wires; 14 to 15 inches between centers is preferable. In general, the wider spacings are common on four-pin arms and the narrower on eight-pin. The spacing of pins next to the pole must be such that sufficient room is left for linemen to get up through the lower wires safely to work on the upper arms, 30 inches being required between pole pins. The dimensions and spacings of standard crossarms as recommended by the National Electric Light Association are shown in Fig. 31.

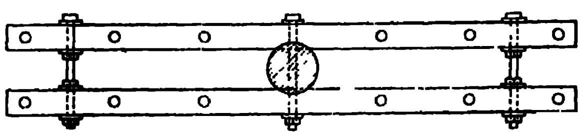


Fig. 32 Double-Arm Construction

Side Arms. In cities where alleys are used for distributing lines the presence of buildings necessitates the use of side arms, or alley arms, as they are commonly known.

Double Arming. At corners, terminals, and other points where there is an unusual strain the poles should be fitted with a double arm equipment so that the strain will be carried by more than one support. The arms should be bolted together at the ends by spreader bolts having nuts which clamp the arms on both sides, Fig. 32.

Arm Bolts. Arms are fastened to the pole by bolts. The bolt is fitted with a nut and washer on both ends and should be ⅝ inch in diameter and from 12 to 16 inches long, depending upon the diameter of the pole.

Arm Braces. In order to hold the crossarm firmly in a horizontal position, braces must be provided. These are usually of strap iron about ¼ inch by 1 inch by 26 to 30 inches long. A

side arm must be supported at a point farther out from the pole than a center arm, and it is therefore usual to use a brace of angle iron such as that shown in Fig. 33.

Pins. Pins of wood are preferred for distribution work. Locust, elm, oak, and other woods are commonly used, but locust is superior to all others in strength and durability. Pins should be coated with white lead before being put into the pin holes and should then be secured by a sixpenny galvanized nail. It is

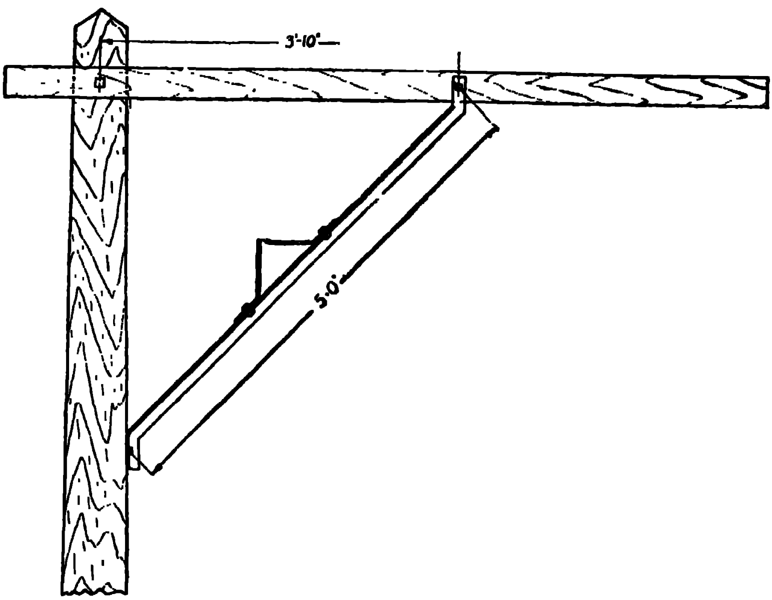


Fig. 33. Side Arm Brace Construction

usually best to fill all pin holes with pins in the shop before the arms are sent out for use.

Insulators. The most common type of insulator used in distribution work is that known as the deep-groove double-petticoat insulator of glass or porcelain, Fig. 34. The dimensions of this insulator are sufficient to carry circuits operating at potentials up to 5000 volts safely with standard wooden pins. The groove is ample for any size of weatherproof wire up to No. 0000. The line wire is secured to the insulator by a tie wire laid in the groove and twisted around the line wire several times at each side of the insulator.

Clearance from Trees. Where primary lines are carried through trees, care must be taken to provide clearance from limbs. If the necessary permission can be obtained for judicious trimming, it should be done. When the trees are very large, it is usually preferable to carry the wires through the larger limbs below the main body of leaves. When trimming is not permissible to a sufficient extent to be effective, tree wire having about $\frac{3}{32}$-inch rubber insulation covered with a layer of steel tape may be used.

Arrangement of Wires. The position of wires on the cross-arms should be assigned according to a systematic plan. Circuits should be kept on the same side of the pole and in the same pin spaces throughout their course to facilitate location of trouble and to eliminate the possibility of accidents. In general, through lines and the highest voltages should be carried on the upper arms; and distributing mains and arc circuits supplying lamps in the vicinity should be carried on the lower arms. The lower voltages should be carried on the lower pole pins. Where side arms are used, the primary wires should be carried at the outer end of the arm. The wires of a given circuit should be carried on adjacent pins, and the neutral of low-tension or secondary wires should be carried in the middle. On three-phase four-wire lines the neutral should be carried at one side of the phase wires and, as far as possible, on one of the pole pins. In carrying connections across the pole for transformers, or services, one side of the pole should be left free for climbing.

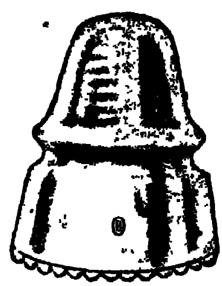


Fig. 34 Deep Groove Double-Petticoat Insulation

Joint Occupancy. The use of a joint line of poles is preferable to separate lines on thoroughfares where there are service drops. With lines on opposite sides of the street the service drops of the lighting company must pass under or through the lines of the signaling company on the other side, and vice versa. Where poles are occupied jointly by electric light and telephone or telegraph companies, the lighting wires should always occupy the upper part of the pole, as the signaling wires are more likely to break than the lighting lines. A clearance of about 4 feet

should be maintained between the lower lighting wires and the telephone wires.

Transformer Installation. Transformers are commonly supported on crossarms by iron hangers, Fig. 35. This class of construction is suitable for transformers of capacities up to 5 kilowatts. With units of 7½ to 15 kilowatts it is usual to use double arm construction for the arms on which the transformer hanger irons are carried. Units of 20 to 40 kilowatts are usually supported by a special 4 by 5-inch arm or by some form of bracketed platform placed below the transformer in such a way as to share a portion of the weight. Single units should be hung in the middle of the crossarm and not at one side. Where two or three transformers are mounted on the same pole, they must be so disposed as to give access to primary cutouts with as little risk as possible to linemen.

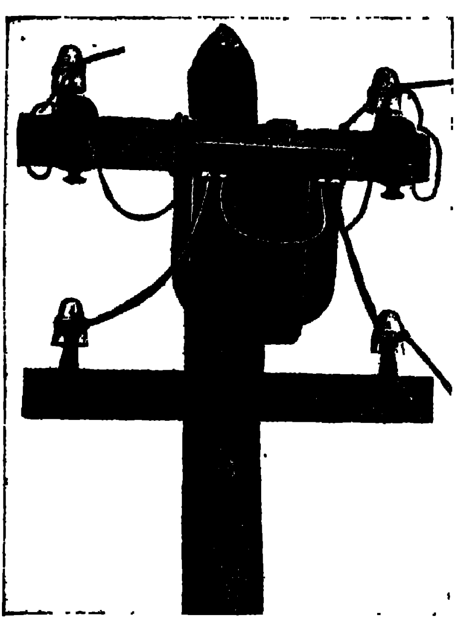


Fig. 35. Installation of Pole Line Transformer

Two or more poles with a platform between, Fig. 36, are used for supporting installations of three transformers of 40 kilowatts each or larger. The poles are reinforced at the butt by concrete to increase their stability against side strains. The weight is carried by two 3 by 10-inch timbers which are bolted to the poles and on which the platform is laid. The primary cutouts are all accessible from one side of the structure.

Service Connections. If there are several services taken from the same pole, the use of a buck arm is best, as services can be taken to both sides in any desired number from one buck arm.

The attachment of service wires to buildings is one of the most troublesome details of distribution work, owing to the varying character of buildings, lengths of drops, and angles of approach.

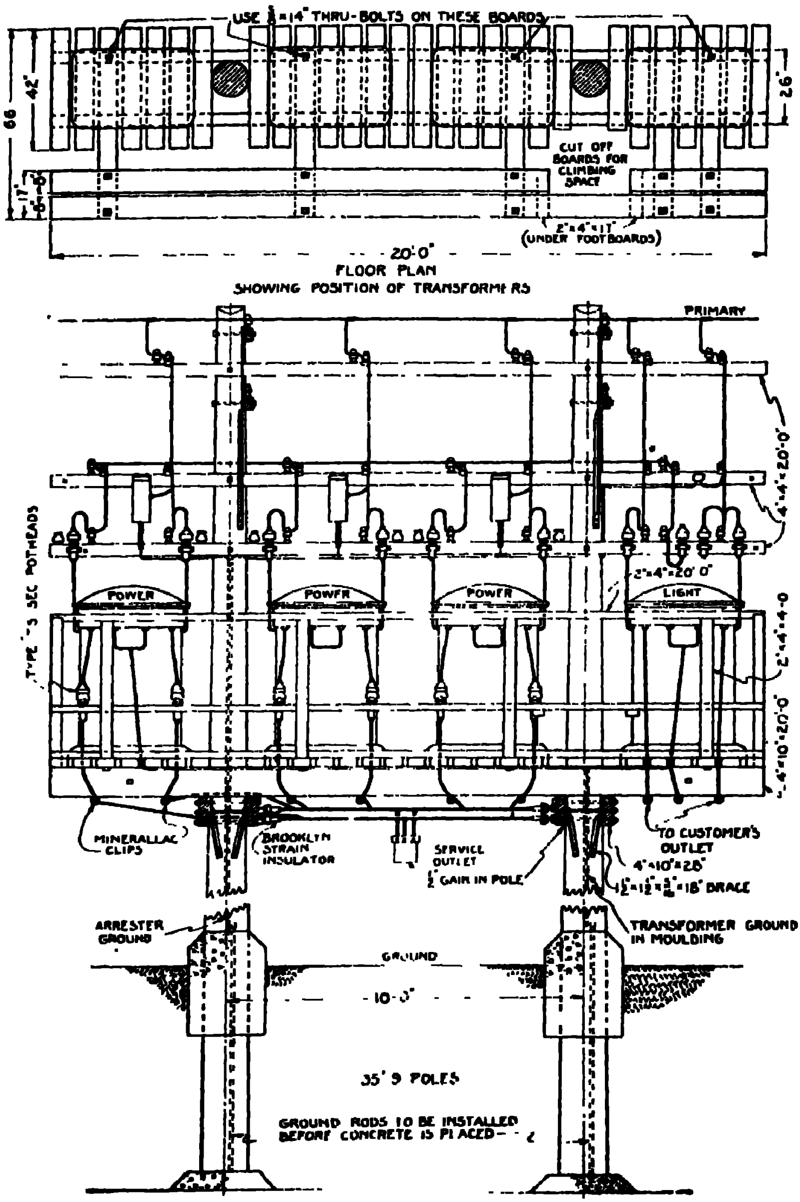


Fig. 36. Transformers Set on Platform

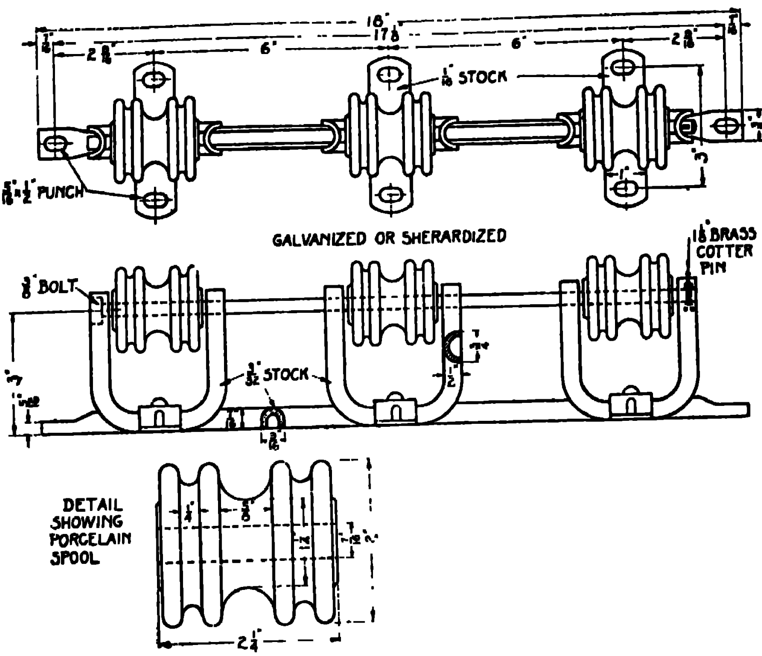


Fig. 37. Wrought Iron Service Bracket

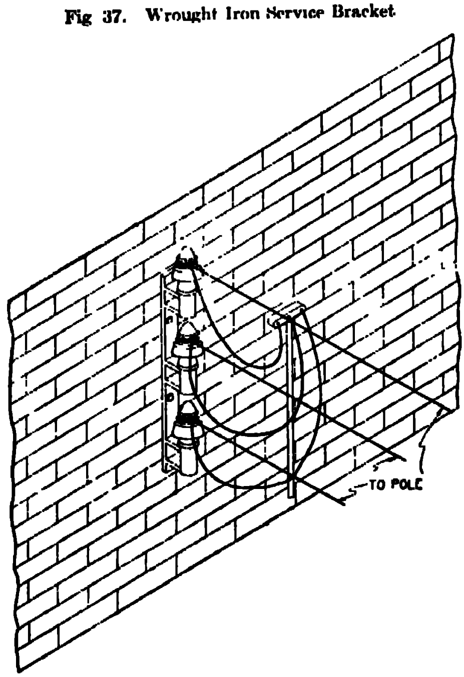


Fig. 38 Service Bracket for Heavy Wires

With frame buildings wooden brackets and spikes are used for spans up to 60 or 75 feet. With brick or stone buildings, however, this construction is not reliable, and holes must be drilled for expansion bolts to support iron brackets. A wrought-iron bracket, one form of which is shown in Fig. 37, is supported by two bolts. For larger services a more rugged malleable-iron bracket is required, Fig. 38.

The installation of secondary mains on vertical racks, Fig. 39, has been introduced in recent years. This construction is well suited to residence districts. It is usual to place a vertical rack on each side of the pole where services are taken off on both sides of the line.

In making a loop on series circuits, an iron fixture—known as a break arm—having two pins and so arranged that it can be used in place of a line pin, is used.

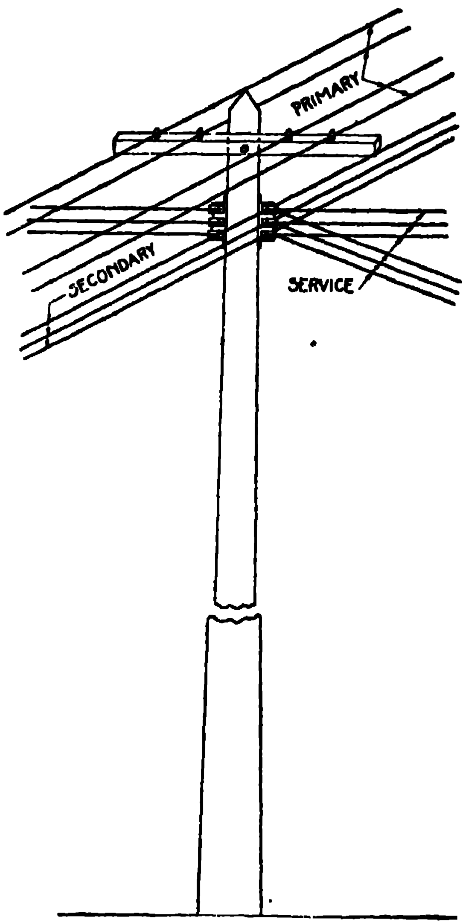


Fig. 39. Secondary Main Carried on Vertical Racks

UNDERGROUND CONSTRUCTION

Extent of Use. Underground construction has been used in the larger cities from the beginning of the electric lighting industry. Considerations of appearance and space prevent the use of overhead lines in the congested parts of large cities, and the greater first cost of underground construction is justified by the increased security to the service of important consumers.

Edison Tube System. The underground system devised by Edison was the earliest one adopted, and it remained standard for low-tension distribution for about fifteen years. This system is discussed under Direct-Current Edison System.

Conduit System. About the year 1897 cables drawn into ducts began to be employed for heavy feeders. This change was made on account of the inability of the tube feeders to carry overloads without causing burnouts. Furthermore the necessity of opening street pavements in each case where repairs were made was objectionable, as several openings were often made before the trouble could be definitely located. Service connections in the newer system are made in much the same way as in the tube services, the joints being enclosed in a T coupling box of iron. In cases where it can be used to advantage such construction is supplanting Edison tube work since the cost of the two systems is about the same.

Construction of Conduit Systems

Types of Ducts. Alternating-current and series arc systems installed in situations requiring underground constructions cannot use a system similar to Edison tubes because of the higher voltages employed. A variety of plans have been tried, but the draw-in conduit system with manholes for handling the cables is the only one which has survived. Among the various forms tried out were ducts of concrete and clay tile. Since these materials are fireproof and of indefinitely long life, they have been used very extensively. In later years there has been produced a fiber duct having ample mechanical strength when surrounded by concrete. This type of duct is made in lengths of about 5 feet, is easily handled because of its light weight, and when laid with concrete between adjacent ducts, makes a durable structure. It has advantages for lines where the cost of transportation and of the breakage of tile duct is large and has been used for light and power distribution to a considerable extent.

Laying Out a Conduit Line. In the design of a draw-in duct system the number of ducts and the size and the location of manholes are the important considerations. There must be enough ducts to care for distributing feeders and through lines and to make an allowance for future requirements.

The reservation of duct space for future requirements is very important if the system is growing, as the expense of adding a few ducts at a later date is much larger than that of laying them at the outset. It is desirable to lay sufficient ducts to care for requirements for at least five to ten years ahead. It is usual to lay not less than four ducts in a line, except on streets where there is no probability that the line will ever become part of a through line. In such cases two ducts will meet the requirements.

The maximum number of ducts which it is advisable to put into a line is governed chiefly by considerations of safety to the cables. With a large number of ducts in one line the number of cables exposed to injury in case of a manhole fire is so great that the resulting interruption of service may be very serious. It is therefore good practice to limit duct lines to about twenty-four ducts as a maximum in the vicinity of stations where large numbers of ducts must be provided.

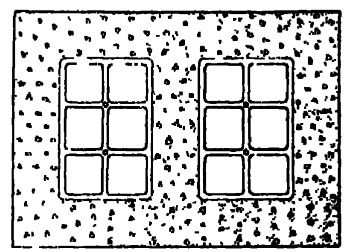


Fig. 40. Cross-Section of Duct Line

In arranging the duct formation, it is desirable to place the ducts so that the cross-section will be approximately square since this requires a minimum of concrete in the outer casing. However, with twelve, sixteen, twenty, or twenty-four duct lines it is preferable not to exceed four ducts wide. With ducts arranged as in Fig. 40 a double row of cables may be trained around each side of the manhole, making all cables accessible for repairs.

Near a station where the energy available in case of a cable burnout is sufficient to damage the conduit system it is desirable to separate the middle vertical rows of lines having twelve or more ducts by filling the space with about 3 inches of concrete. This limits the cable damage to one-half of the line.

Location. The draw-in system involves the construction of vaults called manholes at points where the cable must be jointed. Where long runs occur without intersecting other lines, manholes must be so spaced as to permit the cable to be drawn in without damage to the insulation. This requires that they be not over 500 feet apart.

As far as possible manholes should be located with a view to their being used as intersection points later; that is, they should be located so that any conduit line built later on an intersecting street may be connected with existing manholes.

The number of manholes required for underground service connections is dependent somewhat upon local conditions but must usually be sufficient to permit service pipes to be brought in at intervals of 100 to 200 feet, Fig. 41.

Design. Manholes located in a straightaway line should be so designed that the cables may be trained around the sides with a minimum of waste cable and yet with sufficient space to enable a jointer to work efficiently. Such a manhole is illustrated in Fig. 42. Where the line intersects another duct line, a d

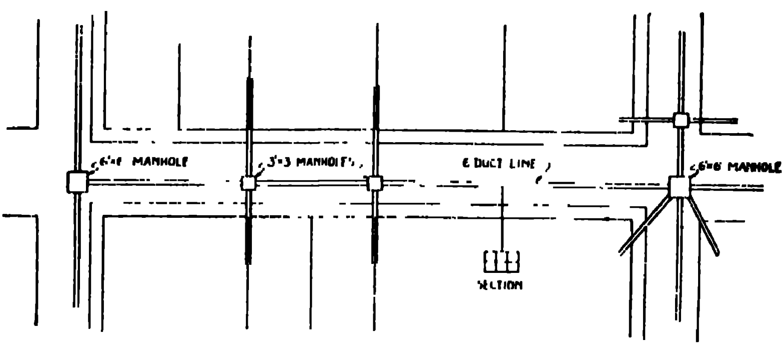


Fig 41. Conduit Line and Service Connections

must be used which affords room for working and also for cables going both ways. At such points a square design is preferable, Fig. 43.

It is usual to provide manholes 5 feet by 5 feet at junctions where there are eight ducts, that is, where two four-duct lines cross; 6 feet by 6 feet where there are twelve to eighteen ducts; 7 feet by 7 feet where there are twenty or more ducts; and still larger manholes when the case so requires. The size and shape of manholes in congested districts are often governed by local obstructions such as gas or water mains.

The depth of manholes must be sufficient to give head room and yet should not be so great as to carry the floor of the manhole below the sewer level. Small distribution manholes which are used only for service connections may be 5 feet deep, while

junction manholes should be 6 or 7 feet from roof to floor. In some cases a shallow form of manhole known as a handhole is

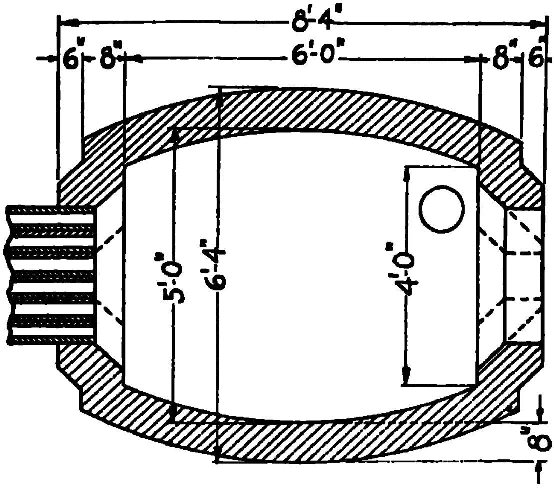


Fig. 42. Through Line Manhole

used for distribution laterals. Handholes are placed above the conduit line, so that only the top row of ducts enters a handhole. The distributing mains are thus accessible for service taps, but

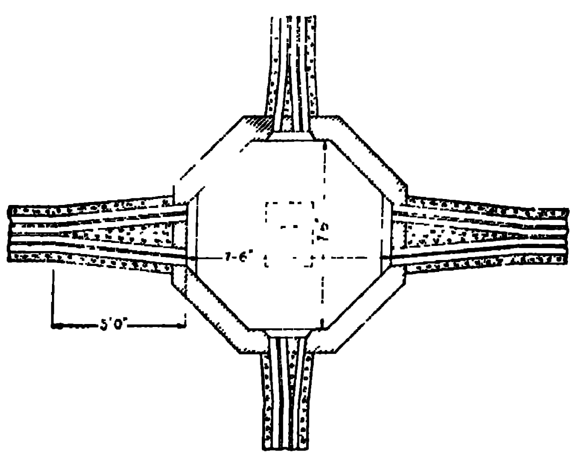


Fig. 43. Manhole for Intersections

the through lines in the lower ducts are not exposed. Handholes should have covers large enough to afford access to the distributing main.

Service Connections. The arrangement of service laterals or subsidiary connections from the main duct line to consumer's premises is important as such connections represent a large part of the underground investment in congested districts.

Where service laterals can be spaced 100 feet or more apart, a single duct line is sufficient to care for the service on both sides of the street. Lateral connections are run to each side from the service manholes.

The arrangement shown in Fig. 41 is based on a street 66 feet wide, with 34 feet between curb lines. This is the most feasible arrangement in streets where there are car tracks under which laterals must be carried. The construction shown in

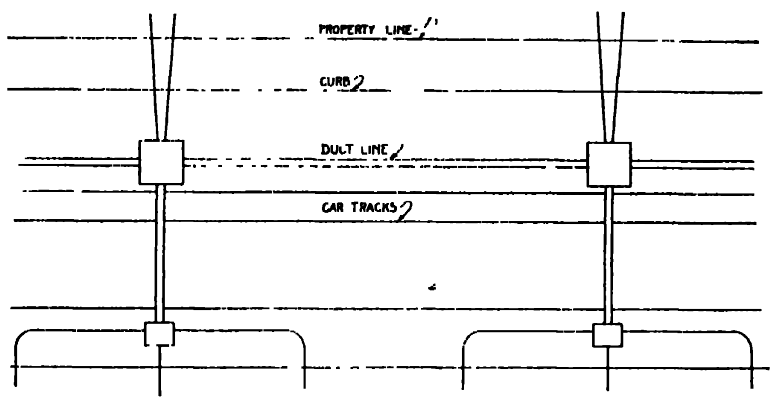


Fig. 44. Service Handholes in Parkway

Fig. 44 is an advantageous plan where there is a parkway in which the laterals can be laid, no paving being disturbed in making new service connections.

Location of Duct Lines. In the location of a duct line the presence of other piping or duct systems, sewer manholes, and the like must be taken into account. It is desirable to select the side of the street which is least obstructed in this manner. Sewers and duct systems may be located by the manhole covers which appear on the surface. In crowded streets and where records are not available time is saved by excavating a test trench across the street at several points for the purpose of locating the piping and other systems which cannot be identified from the surface.

Forms of Duct. Conduit is made in single- or multiple-duct pieces, the former usually about 18 inches in length and the latter 36 inches. The dimensions of ducts in general use are shown in Fig. 45. Multiple duct is somewhat cheaper than an equal number of single ducts, and it requires less labor to lay it. In a large system it is considered preferable to use single duct as this better protects the cables in adjacent ducts from injury in

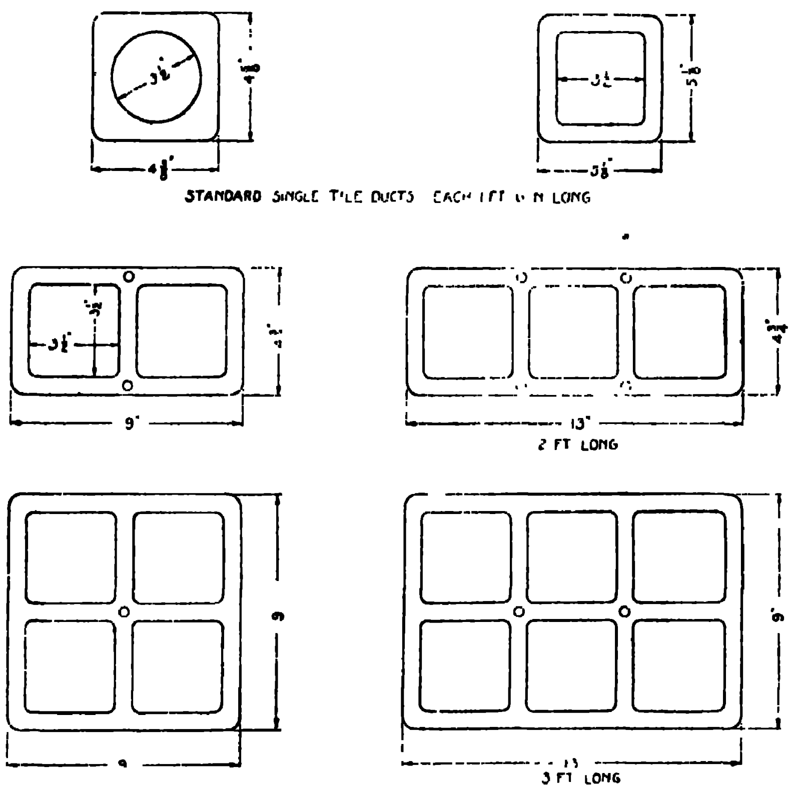


Fig. 45. Standard Tile Ducts

case of burnouts. The single duct also has the further advantage that the joints may be staggered.

Installation of Conduit Lines. In laying a line of ducts the grades must be carefully established so that the duct line will tend to drain toward the manholes. If pockets are formed, the standing water is likely to freeze and injure the insulation of the cables and break the tile. It is important that manholes in

which work must be done frequently or in which transformers or junction boxes are installed be connected to the sewer. The accumulation of water in such a manhole may seriously delay emergency repair work.

The conduit line must be protected, when laid in public thoroughfares, from external injury. It should also be made secure against the possibility of getting out of alignment. It is therefore usual to surround conduit lines with concrete on all sizes to a thickness of 3 inches. This makes an envelope thick enough to support short sections around which later excavations may be made and also protects the tile from the laborer's pick. With lines built in parks or in roadsides it is sometimes sufficient to lay the ducts on 2-inch creosoted plank with a similar plank over the top of the ducts. Such construction is less expensive in first cost and, if not disturbed, is quite durable.

Where excavations can be made without interference with other piping or duct systems, manholes may be economically constructed of concrete according to a standard design for which forms may be used. Otherwise forms are not practical, and walls must be built up of brick. In most cases the floor may be made of concrete as no forms are needed. The brick should be of the quality known as sewer brick and should be laid up with a good cement mortar, an 8-inch wall being ample for the requirements in most cases. The roof must have sufficient strength to support the heaviest street traffic, and its design therefore varies with the size and shape of the manhole.

Cost of Conduit Construction. The cost of installing a conduit system may be analyzed into three principal items: the cost of the ducts; the cost of the manholes; and the cost of repaving. The cost of the ducts and the manholes is readily determined for the different sizes of duct lines and manholes, while the cost of repaving depends on the character of the paving to be replaced.

With labor at 30 to 35 cents per hour and duct at 6 cents per foot the cost per duct foot and per trench foot for duct lines of various sizes is shown in Table IX, macadam paving being estimated at 80 cents per square yard and brick or asphalt at $4.50 per square yard.

TABLE IX

Cost of Underground Conduit

Number of Ducts	Cost per Duct Foot			Cost per Trench Foot		
	No Paving	Macadam	Brick or Asphalt	No Paving	Macadam	Brick or Asphalt
2	$0.36	$0 41	$0.78	$0 72	$0.88	$1.56
4	0 33	0.37	0.57	1.32	1.48	2.28
6	0.30	0.33	0.48	1.80	1.98	2.88
9	0.29	0.32	0 44	2.61	2.88	3.96
12	0.28	0.30	0.40	3 36	3.60	4.80
16	0.27	0.29	0.36	4.32	4.64	5.76
24	0.26	0.32	0.32	6.24	6.48	7.08

The cost of manholes without paving with brick work at $19.00 per cubic yard, labor of excavation at 35 cents per hour, and concrete at $10.50 per cubic yard is shown in Table X. There is some repaving expense in connection with manholes in addition to that required for the ducts, as the opening is considerably wider. This item is added at the foot of the table for convenience.

The plan of a duct line having been determined, the cost may be estimated from Tables IX and X for the conditions prevailing in any case.

Example. What will be the cost of installing a four-duct line in a street paved with brick for a distance of 1200 feet, including three 4×5×6 and one 6×6×6 manholes and four 3×3×4 handholes? The brick paving costs $4.50 per square yard. From Tables IX and X the cost of the installation will be found to be as follows:

1200 trench feet	four-duct line	at $ 2.28 =	$2736.00
3 manholes	4×5×6	at $216.15 =	648.45
1 manhole	6×6×6	at $282.05 =	282.05
4 handholes	3×3×4	at $104.80 =	419.20
	Total		$4085.70

In addition there would usually be service laterals from the handholes to buildings. If there were ten two-duct laterals 20 feet long, the cost of laterals at $1.56 per trench foot would be 10×20×$1.56, or $312.00 additional.

Types of Cable. Cables used for the underground distribution of electricity consist of a conductor or group of conductors suitably insulated and enclosed in a lead sheath for protection

TABLE X

Cost of Manholes

	3×3 4 Feet Deep	4×5 6 Feet Deep	6×6 6 Feet Deep	8×8 6 Feet Deep
Excavation and Removal	$ 6.30	$ 15.75	$ 33.25	$ 51.90
Brickwork at $19.00 per Yard	31.70	66.40	85.50	110.80
Concrete at $10.50 per Yard	10.50	15.25	25.60	42.35
Roof Iron at $0.06 per Pound	6.30	7.75	10.70	13.60
Sewer Connection and Trap	.....	35.00	35.00	35.00
Frame and Cover	28.00	28.00	28.00	28.00
Supervision and Incidentals	4.00	7.50	10.00	14.00
Totals	$ 86.80	$175.65	$228.05	$295.65
Paving Required, square yards	4	9	12	16
Cost of Paving at $0.80	$ 3.20	$ 7.20	$ 9.60	$ 12.80
Total with Paving at $0.80	90.00	182.85	237.65	308.45
Cost of Paving at $4.50	18.00	40.50	54.00	72.00
Total with Paving at $4.50	104.80	216.15	282.05	367.65

from moisture. If the cable is laid without the protection of a conduit system, it is further protected from mechanical injury by an armor of steel tape or wire.

Cables having but one conductor are known as single-conductor cables, those having two conductors are known as duplex or twin, and those having three, as triplex, or three-conductor, etc. Duplex cables are those in which the conductors are spirally arranged in the lead sheath to make cable of circular cross-section. Twin cable is that in which the two conductors are arranged in one plane, making an oval cross-section. Two-conductor and three-conductor cables are also made with a concentric arrangement.

Where it is necessary to get the maximum cross-section of copper within a given diameter of lead sheath, the copper conductors are stranded so as to make a cross-section shaped like a sector of a circle.

Cables having as many as twelve conductors have been used to some extent as main runs of series lighting circuits. The use of multiple-conductor cables is generally advantageous because of the saving in the cost of the lead sheath. However, there are certain disadvantages incidental to taps and joints which tend to offset some of the advantages. Single-conductor cable is used

where taps are required, as in distributing mains, while multiple-conductor cables are used for through lines where taps are not made.

Concentric cables are used in preference to duplex where the conductors are over No. 0 A.W.G., as the cable is not so difficult to bend. The greater facility of jointing with duplex makes its use preferable in the sizes below No. 0.

Cables carrying loads of 200 amperes and upward are subject to inductive action when single-conductor. There may be an appreciable difference of potential between the lead sheaths of the cables and, where they are in contact with each other, a flow of current sufficient to cause injury. This can be prevented by the use of jute over the lead, though this is objectionable in case repairs are necessary owing to the tendency of such cables to stick in the duct. The preferable method with cables up to 400,000 CM is to use a multiple-conductor cable.

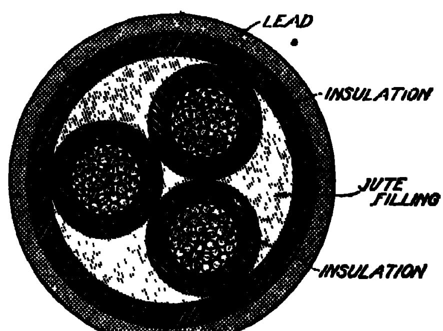


Fig 46 Section of Polyphase Cable

Transmission lines for voltages up to 25,000 may be carried in three-conductor cable with a thickness of insulation on each conductor sufficient for the voltage between phases. Another layer of insulation is placed over all three conductors, Fig. 46.

Insulation. Cables are insulated according to the voltage for which they are intended and the conditions of installation and service. Three kinds of insulating material are in general use, rubber, oiled paper, and varnished cambric.

Rubber. Rubber is used because of its ability to withstand moisture, and its elasticity, which is of value in training cables around corners of manholes. With voltages above 2500, however, rubber is affected by the presence of static discharges and has a tendency to lose its insulating qualities.

Oiled Paper. The disadvantages of rubber, together with the high cost of good rubber, led to the practice of insulating cable

TABLE XI

Weight and Diameter of Single Conductor Cables—600 Volts

(PAPER- AND LEAD-COVERED)

Size A.W.G.	Thickness of Paper (in.)	Outside Diameter (in.)			Weight per Foot (lb.)	
		Copper	Paper	Lead ($\frac{4}{32}$ in.)	Copper	Total—Copper, Paper, Lead
6	$\frac{4}{32}$	0.180	0.430	0.680	0.085	0.922
4	$\frac{4}{32}$	0.234	0.484	0.734	0.140	1.069
2	$\frac{4}{32}$	0.295	0.545	0.795	0.221	1.256
0	$\frac{4}{32}$	0.378	0.628	0.878	0.338	1.920
00	$\frac{4}{32}$	0.425	0.675	0.925	0.426	2.111
000	$\frac{4}{32}$	0.475	0.725	0.975	0.532	2.326
0000	$\frac{4}{32}$	0.524	0.774	1.024	0.650	2.551
CM						
200000	$\frac{4}{32}$	0.505	0.755	1.005	0.614	2.473
250000	$\frac{4}{32}$	0.568	0.818	1.068	0.790	2.786
300000	$\frac{5}{32}$	0.637	0.949	1.199	0.949	3.243
350000	$\frac{5}{32}$	0.680	0.992	1.242	1.092	3.484
400000	$\frac{5}{32}$	0.735	1.047	1.297	1.224	3.738
450000	$\frac{5}{32}$	0.777	1.089	1.339	1.343	3.949
500000	$\frac{5}{32}$	0.820	1.132	1.382	1.550	4.251
600000	$\frac{5}{32}$	0.900	1.212	1.462	1.874	4.752
750000	$\frac{5}{32}$	1.020	1.332	1.582	2.331	5.473
800000	$\frac{5}{32}$	1.037	1.349	1.599	2.462	5.642
900000	$\frac{5}{32}$	1.096	1.408	1.658	2.815	6.126
1000000	$\frac{5}{32}$	1.157	1.469	1.719	2.138	6.583
1250000	$\frac{5}{32}$	1.296	1.608	1.858	3.831	7.584
1500000	$\frac{6}{32}$	1.412	1.787	2.037	4.681	8.969
2000000	$\frac{6}{32}$	1.652	2.027	2.277	6.237	11.077
2500000	$\frac{7}{32}$	1.848	2.285	2.535	7.674	13.221

TABLE XII

Weight and Diameter of Three-Conductor Cables

(PAPER- AND LEAD-COVERED)

Size A.W.G.	3000 Volts		5000 Volts		7000 Volts		13500 Volts	
	Weight per 1000 Feet (lb.)	Diameter over Lead (in.)	Weight per 1000 Feet (lb.)	Diameter over Lead (in.)	Weight per 1000 Feet (lb.)	Diameter over Lead (in.)	Weight per 1000 Feet (lb.)	Diameter over Lead (in.)
6	1874	0.979	2190	1.114	3199	1.508	5742	2.100
4	2270	1.083	2597	1.218	3646	1.608	6299	2.206
2	2837	1.213	3188	1.345	4274	1.740	7052	2.335
1	3405	1.314	3583	1.441	4705	1.837	7561	2.433
0	3864	1.459	4045	1.525	6110	1.984	8144	2.515
00	4420	1.553	4610	1.622	6755	2.080	8841	2.608
000	5081	1.663	6106	1.795	7513	2.190	9657	2.720
0000	6700	1.852	6978	1.919	8446	2.315	10663	2.845

with strips of oiled manila paper wrapped spirally about the cable. Enough layers are used to insulate at the given voltage and to give proper mechanical strength when the cable is bent. This type of insulation is standard for high-voltage cables as it has a high dielectric strength and is less expensive than rubber. It is also used for low-voltage cables in many cases. Paper insulation is capable of withstanding higher temperatures than rubber, which gives it an advantage for low-tension feeders. In Tables XI and XII, respectively, are given the weights and diameters of single-conductor and three-conductor paper- and lead-covered cables of various sizes.

Varnished Cambric. Varnished cambric forms a somewhat more elastic insulation than paper and is less susceptible to moisture while exposed. It is more expensive than oiled paper but less expensive than rubber and has replaced paper in some classes of work where there is likely to be exposure to moisture.

Thickness of Insulation. The thickness of insulation is determined by considerations of both mechanical and dielectric strength. The bending of cables in manholes places a strain on the insulation which it must be able to withstand without its dielectric strength being affected. The radius of bending should not be less than six to eight times the diameter of the cable. With cables for 600 volts and under the minimun thickness which is safe for bending is adequate for dielectric strength. For 2200-volt distribution single-conductor cables usually have $\frac{5}{32}$-inch insulation. Cables for 6600 volts have about $\frac{8}{32}$-inch insulation, and those for 15,000 volts about $\frac{12}{32}$-inch.

Assigning Cables to Ducts. A uniform method of selecting ducts for the various cables should be followed as far as possible. Cables used in local distribution should be given such a place, preferably in the top row, that handholes can be built for service laterals without sinking them below the top row of ducts. The lower ducts are thus left for through lines which may be trained through the manholes below junction boxes.

Installation of Cable. *Drawing-In.* Cables are drawn into ducts by means of a line attached to a source of power. This line is put through the duct by the use of detachable rods of wood about 3 feet long and 1 inch in diameter, which are pushed

into the duct as they are joined together. They are then drawn through with the pulling line attached and are disjointed at the other end. The cables are secured to the pulling line by baring the copper and making a secure mechanical connection or by means of patent cable grips, which are more quickly attached and removed.

When the cable pulling line is ready, it is run over pulley wheels out of the manhole and to the source of power. The reel of cable is set up so that it will revolve and pay out cable as it is drawn in. Men are placed at the reel and in the manhole to guide the cable into the duct and prevent its sheath being injured.

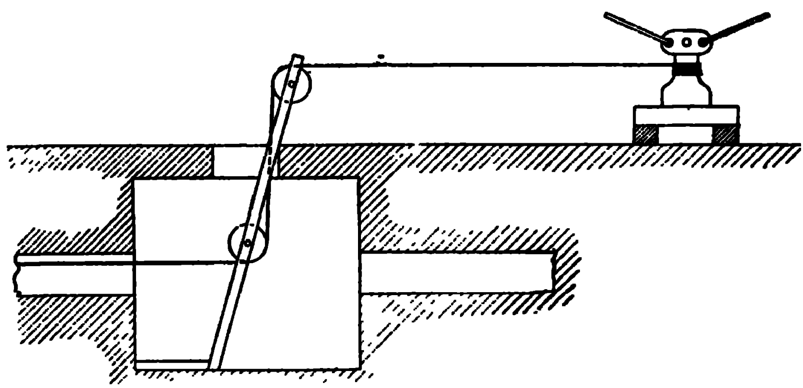


Fig 47 Cable-Drawing Equipment

Power for pulling is supplied in various ways. With short runs a few men can draw the cable in. With runs of 300 to 500 feet the power is usually a capstan manned by six or eight laborers, Fig. 47. Where several cables are to be drawn into one duct they are installed simultaneously by securing them to one line.

Small cable is put up on reels and cut to fit as it is drawn in, but a length of about 400 feet of three-conductor high-voltage cable fills a reel. It is therefore usual to order such cable in specified lengths. The distance from center to center of the manholes plus the amount needed for training around the walls of the manholes and splicing is the length to be ordered.

Training Cables. The training of cable through manholes must be done carefully to avoid sharp bends, tangled relations

with other cables, and the possibility of injury by the workman while getting in or out of the manhole. It is customary to support cables on iron racks hung on the brickwork of the walls.

It is usual to protect cables in manholes to prevent the communication of trouble to other cables. This is done by wrapping them with asbestos tape or with manila rope plastered with cement.

Cable Jointing. The work of jointing requires the services of an expert, especially with high-tension paper cables. In jointing cables the lead sheath is removed 5 to 10 inches back from the end and enough of the copper bared to permit a good soldered connection to be made. The bare parts are wrapped with tape of the same material as the insulation until the equivalent of the cable insulation has been applied. A lead sleeve which has

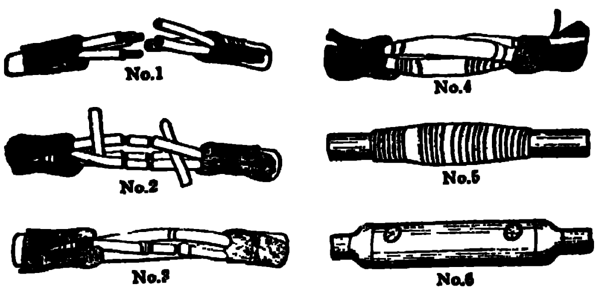


Fig. 48. Steps in Jointing Lead-Covered Cables

previously been slipped back over one of the cables is now wiped on so as to enclose the joint. The air spaces around the joint are then filled by pouring hot insulating compound into a small hole in one end of the sleeve. A similar hole is left open in the other end of the sleeve to allow air to escape easily while pouring in the compound. The openings in the lead sleeve are then closed by soldering, thus sealing the joint from moisture. The various operations for jointing a three-conductor cable are illustrated in Fig. 48. If any sign of moisture appears in either end of the cable, the cable should be cut back, or it may be necessary to drive the moisture off by heating the cable with a blow torch several feet back from the end.

Where a tap is to be taken off, the sleeve may be arranged at right angles in the form of a T or at a tangent, as a Y joint.

The T joint is usually difficult to dispose of on the manhole wall without straining the sleeve, while the cable from the Y joint may be trained along with the cable to which it is tapped.

Cable Terminals. In systems in which part of the lines are underground it is usual to run feeders underground for some distance from the station and connect with overhead lines in the more scattered areas. Where alley distribution is general the

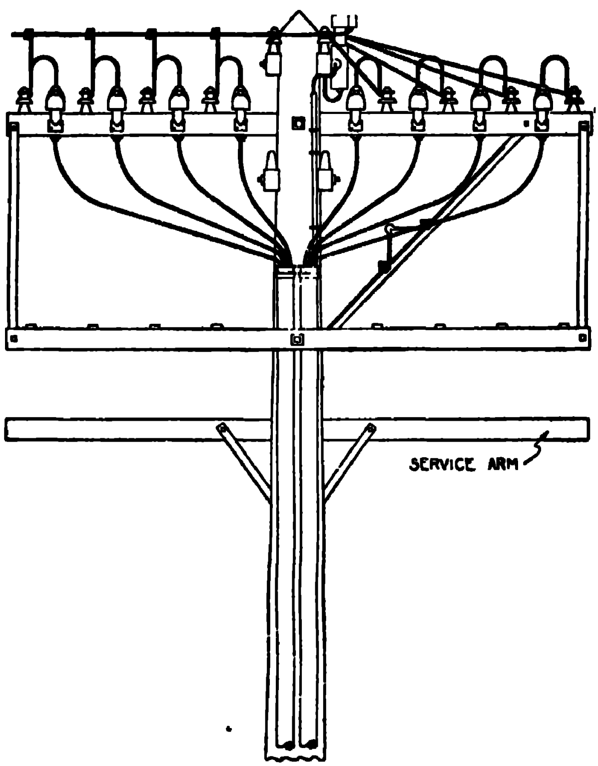


Fig. 49 Single Conductor Pothead Installation

main lines are placed underground on streets and the local distributing taps taken off to overhead lines in alleys. In other locations lines must be carried underground across a boulevard, railroad, or stream.

Pole terminals where underground cables are connected with overhead lines must be protected by potheads, and the type of cable terminal embodying porcelain sleeves has been quite suc-

cessfully used for the purpose. The porcelain sleeve is placed about the end of the cable and the conductor is equipped with a slip joint, by which it can readily be connected to or disconnected from the overhead conductor. The tube is covered at the top by a porcelain cap which serves the double purpose of protecting the tube from the weather and holding one of the connecting metals. The tube is filled with a suitable insulating compound to protect the cable insulation from moisture, and the top of the cap is well taped and painted so that no rain can enter around the overhead wire. A single-conductor pothead installation appears in Fig. 49. The device is also adapted for use with multiple-conductor cables either inside or out of doors, an outside type of three-conductor terminal being shown in Fig. 50.

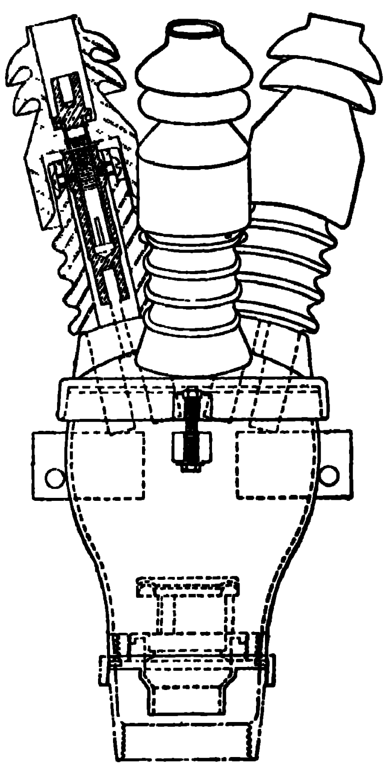


Fig. 50 Three-Conductor Cable Pothead

Emergency Disconnectives. Primary distributing feeders and mains which are underground must be provided with suitable disconnectives for testing purposes and for the isolation of sections of the mains when taps are being connected or repairs made. This work cannot be done while the cable is alive, and the disconnectives must therefore be so placed that sections may be taken out of service with as little interruption of service as possible.

The mains radiating from a feeder center of distribution should be so equipped that the feeder may be isolated from the mains. A scheme of connections such as that shown in Fig. 16 is necessary where complete isolation is required.

In the case of important consumers where two sources of supply must be maintained it is desirable to do the transferring

on the primary side to save duplicating transformer investment. In such cases an arrangement such as that indicated in Fig. 51 is desirable.

In emergency switching there is little occasion to open the circuit under load. If the service has been interrupted, the load is off entirely. If the switching is done in connection with construction work, it must usually be arranged for an hour when the load is light. For these reasons it is not essential that oil break

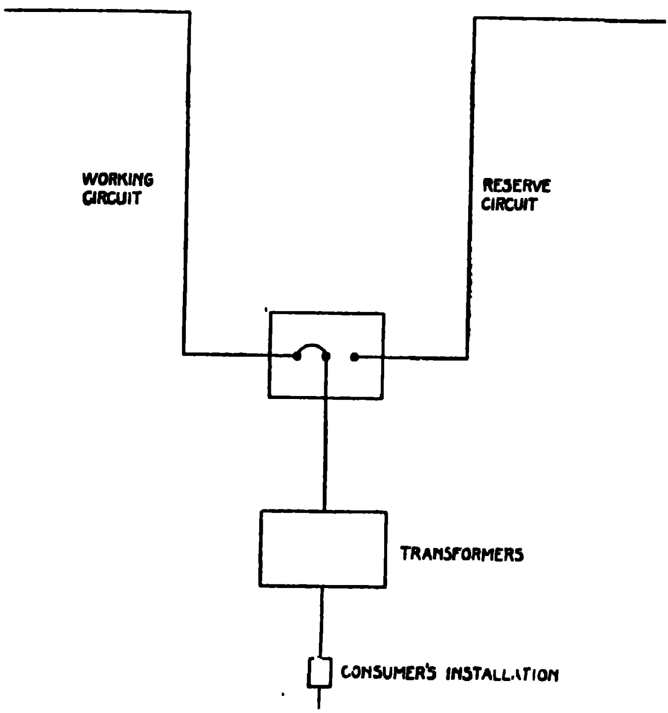


Fig. 51. Emergency Switching for Large Consumer

switches be used, although they are preferred in some cases where switching under load may be necessary at times. Types of disconnectives which utilize an air break are therefore quite commonly used, and detachable potheads such as those above described serve the double purpose admirably.

In Fig. 52 is illustrated a switching box in which multiple-conductor cables are terminated under compound in the box, with the individual conductors brought to the lower end of porcelain

tubes in which contacts are carried. The terminals of each circuit are brought to the outer row of tubes, and the transformer is connected to the middle row. When the source of energy is to be transferred, the cap is lifted and placed in the opposite position.

For a treatment of underground transmission cables between the central station and the various substations in large cities see the article on "Electrical Transmission Lines."

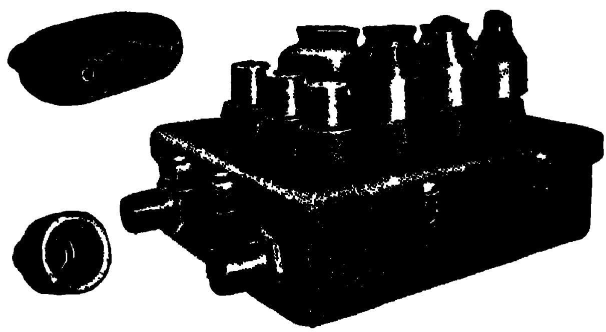


Fig. 52. Emergency Switching Box

LAYING OUT SYSTEM FOR TOWN

Preliminary Assumptions. The procedure in laying out a distribution system for a town of about 2000 people will be described for the purpose of illustrating the principles outlined in the foregoing text. It is assumed that the town is supplied by a transformer substation from a 33,000-volt transmission line passing through it along the railroad right of way. The substation contains three 50-kilowatt transformers, a potential regulator, a series street lighting transformer and regulator, and the necessary switching equipment, lightning arresters, etc.

Determining Size of Substation. *Survey of Prospective Consumers.* In determining what should be the size of the substation, a survey is made of the town with the aid of a map on which are marked the number of probable users of each kind in each block. The appearance of this map on the completion of the survey is as illustrated in Fig. 53. The load chargeable to each class of consumers is then determined by summarizing the data as follows:

Residences, 337, with an average connected installation of 800 watts each, or 270 kilowatts.

Commercial consumers, 30, with an average connected installation of 1000 watts each, or 30 kilowatts, and including stores, shops, offices, halls, and churches.

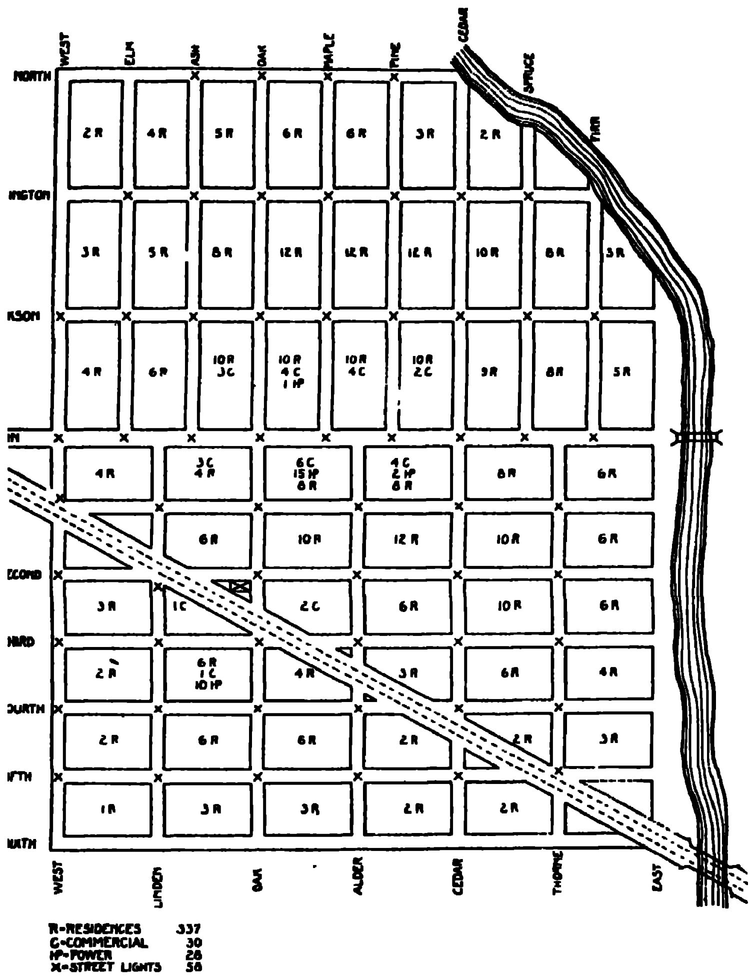


Fig. 53. Survey of Prospective Users of Electricity

Power users, 4, with an aggregate installation of 28 hp.

Street lighting, 60 series tungsten lamps, of which 16 are 300-watt units (those on Main Street in the business section and at the railroad crossings) and 44 are 150-watt lamps (those in the residence sections).

Load on Substation. The demand made by the 337 residences will be about 20 per cent of the connected load, that is, 0.2×270,

or 54 kilowatts; that made by the commercial consumers, which are principally stores, may be as much as 66 per cent of the connected load of 30 kilowatts, or 20 kilowatts; and that made by the power uses may be 70 per cent of the 28 hp., or 20 hp., which is 15 kilowatts. The street lighting load amounts to 16 lamps at 300 watts (4.8 kilowatts) plus 44 lamps at 150 watts (6.6 kilowatts), or a total of 11.4 kilowatts. These various demands will not, however, be made to their full amount simultaneously. The store lighting will, perhaps, only be on to the full extent on Saturday night, while the residence lighting is likely to be somewhat heavier on another night of the week. The power is used chiefly in daytime and overlaps only part of the lighting even in the winter time. The street lighting, of course, is on every day after dusk and must be allowed for to its full extent.

The load on the substation on the heaviest day of the year might be made up about as follows:

Residence Lighting	0.85×54	$=46.0$ kilowatts
Commercial Lighting	0.90×20	$=18.0$ kilowatts
Power	0.20×15	$=3.0$ kilowatts
Street Lighting	1.00×11.4	$=11.4$ kilowatts
Total		78.4 kilowatts

To the total thus obtained must be added the loss in distributing circuits at the time of the maximum load, including transformers and secondary mains, which would average about 8 per cent for a situation of this kind. This would make the load on the substation 78.4×1.08, or 85.0 kilowatts, after the prospective users have all been connected. The load would perhaps not reach this figure in the first year, but it would be wise to arrange for three-phase service, with the lighting on one phase. This provides for further power load and necessitates but one potential regulator for the lighting load.

Substation Equipment. Since the lighting load exclusive of street lighting is 64 kilowatts, it would be advisable to provide a 75-kilowatt transformer for the lighting phase and a 25-kilowatt transformer for another phase. The street lighting regulator and half of the three-phase power would be carried by this smaller transformer, using the open delta connection. The substation

transformers would have a secondary pressure of 2200 volts as this voltage is to be used in the general distribution about town. In case the power load were increased to over 25 kilowatts, an additional 25-kilowatt transformer would be added (or a larger one if necessary), making the installation straight three-phase. If the lighting load increases to a point beyond the capacity of the 75-kilowatt transformer, it can be divided between two phases and an additional regulator provided, or the 75-kilowatt transformer can be replaced by a 100- or 125-kilowatt unit. The

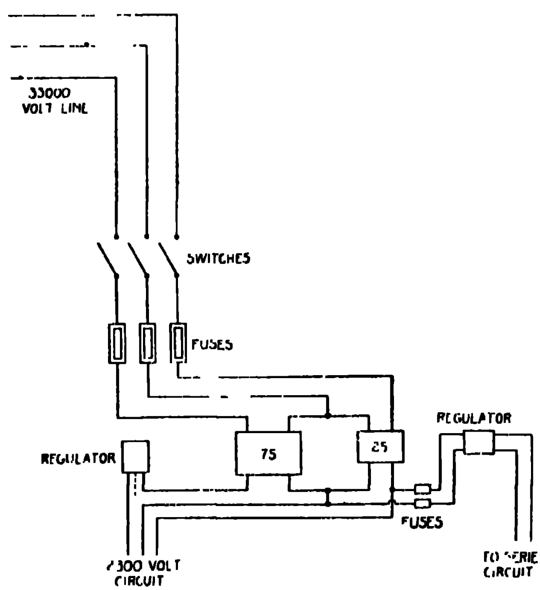


Fig 54 Connections of Substation for Small Town

division between two phases would be preferable as it would balance the load better and would separate the general lighting service so that it would not all be interrupted by trouble on the lighting phase. The connections for the substation as initially installed are shown in Fig. 54.

The substation would be most economically installed out of doors on a platform with a set of disconnecting switches on the 33,000-volt side to be opened when any work is to be done on the high-tension equipment of the substation. The platform should

provide space for a set of electrolytic lightning arresters and for the regulator equipment on the 2200-volt side and should be so arranged as to make easily accessible the automatic adjustments of the regulators, the meter, and the disconnective switches.

Primary Distribution Lines. The primary, or 2200-volt, distribution lines for the general lighting service will be extended to

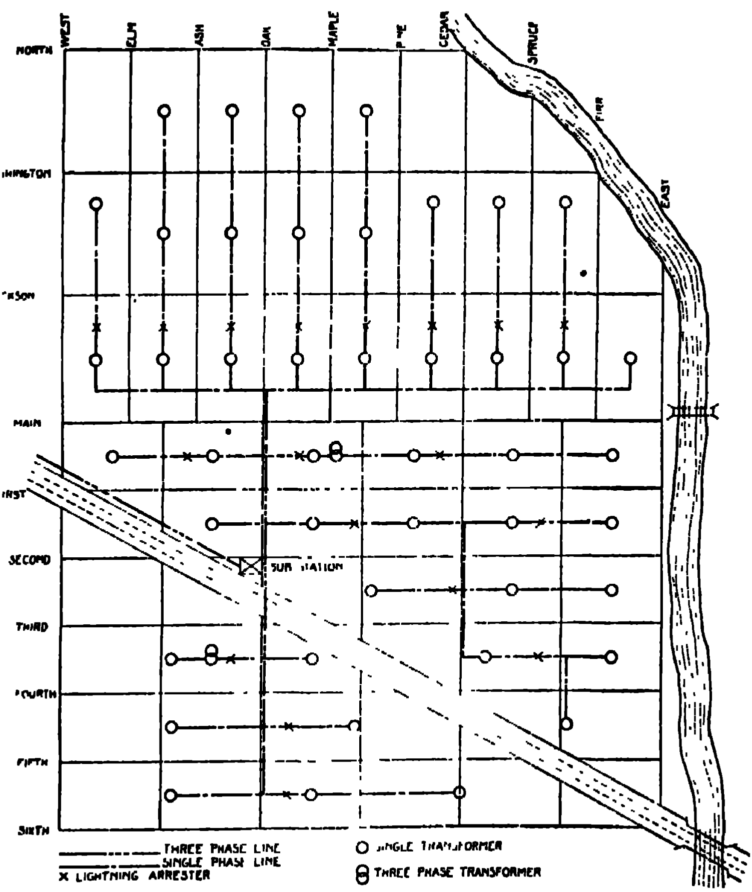


Fig. 55. Arrangement of Primary Distribution Lines

cover each block in which there are three or more users. An outline diagram of the primary lines would be about as shown in Fig. 55, the three-phase parts of the circuit being extended only where there are power users of 5 hp. and more.

The principal part of the load is carried by the branch going north from the substation, which carries about 60 kilowatts. At

2200 volts this is about 27 amperes, and No. 6 wire is large enough for the main line north and south on Oak Street. For

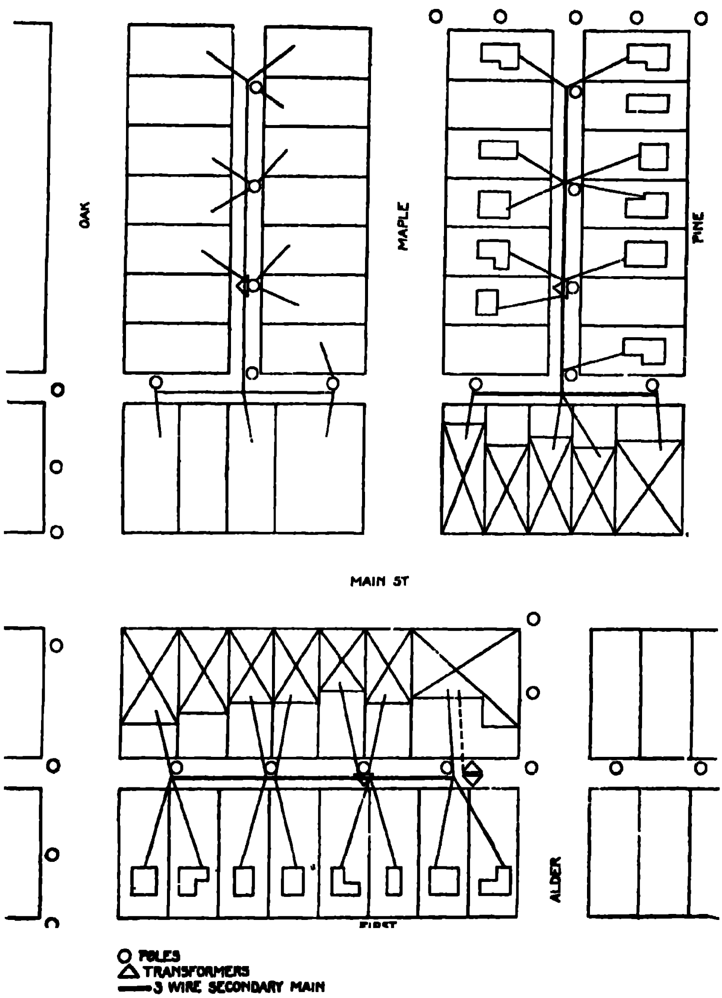


Fig. 56. Typical Secondary Distribution

the branches from the main line No. 8 wire is ample if medium hard-drawn wire is used to insure proper mechanical strength.

Transformers. *Size Required.* The transformer sizes must be ample but not excessive. In blocks where other houses may be

built within a few years it is cheaper in the end to provide a little surplus capacity to save the cost of replacing too frequently.

In the typical block layouts shown in Fig. 56 the size of the transformers may be determined from the combined demand of residence and commercial users. In the block north of Main Street between Maple and Pine Streets, the ten residence users have a demand of 0.2×800, or 160 watts each, and a total of 1600 watts; while the four commercial users have a demand of 0.66×1000, or 660 watts each, and a total of 2640 watts. The sum of these demands is 4.24 kilowatts, and a 5-kilowatt transformer would be advisable to provide for growth.

In the block south of Main Street between Oak and Alder the eight residence users have a load of 8×160, or 1280 watts, and the six commercial users have a demand of 660×6, or 3960 watts, making a total of 5.24 kilowatts, for which a 5-kilowatt transformer may be used. The 15-hp. three-phase motor service is supplied by two 7.5-kilowatt transformers separate from the lighting.

Effect of Use of Electric Appliances. In case some residence owners become users of electric irons, percolators, or other such appliances, there is likely to be some increase in the evening load on the transformer, even though they are used mostly during the daylight hours. The use of this sort of equipment must therefore not be overlooked in this determination of sizes. In the blocks where there are only residence consumers a 1-kilowatt transformer will take care of the lighting load of five or six 800-watt consumers, but if more than two of them should be using a 500-watt iron at the same hour, the transformer would be overloaded. The cost of a 1.5-kilowatt transformer is but 10 per cent more, and it is better to use a 1.5- or 2-kilowatt transformer for more than three or four residence consumers if they are provided with electric household appliances.

Secondary Lines. For the block in which the load requires a 5-kilowatt transformer the current on the three-wire secondary is 23 amperes at the transformer, or about 10 amperes each way (part of the load being taken off at the transformer pole). The drop on a No. 6 three-wire line at 10 amperes for a distance of 220

feet (two spans) is $\frac{10 \times 220 \times 10.8}{26200}$, or 0.88 volt per wire if the load is perfectly balanced. If it is out of balance 5 amperes, there will be a further drop of 0.44 volt, making 1.32 volts drop on one side of the main. With a two-wire service of No. 10 wire to the building there is sufficient additional drop to make the total 2 per cent or more. If it were attempted to extend the secondary into the next block, it would more than double the distance and the current, and the drop with No. 6 wire would be about 4 times 0.88, or 3.5 volts. If the drop is to be kept within 2 per cent, which is the desirable limit for good lighting service, the size of wire will have to be made about No. 2, which is 2.6 times No. 6. The added cost of the larger wire is not offset by any considerable saving in transformer capacity, and it is therefore best to provide a transformer about every 600 feet if there are more than four residence consumers to be served within that distance. In this case the blocks on the edge of town where there are but two or three consumers may be connected by secondary extension to the transformer in the adjacent block. It will be noted in Fig. 55 that primary mains do not enter such blocks.

Street-Lighting Circuit. The use of a separate circuit for the street lighting is desirable to facilitate daily switching. A series circuit of No. 8 medium hard-drawn wire is the most economical which can be provided. Proper lighting on Main Street and at the grade crossings of the main-line railroad passing through the town requires 300-watt lamps. The lighting on Main Street might be placed on ornamental posts with underground connections in the better part of the business district if the public were willing to share the expense. In the residence sections 150-watt lamps are usually found adequate and are placed at each street intersection.

The probable routing of the circuit would be as indicated in Fig. 57, the wires being carried together except at the edge of the system and utilizing pole facilities provided for other circuits as far as possible.

Line Construction. *Location of Poles.* In selecting routes for the lines, the alley system, which is general throughout the town, should be used as far as practicable in order to avoid the presence

of poles on the streets in residence sections. A through line on Oak Street forms a main line from which the branches are readily taken into the alleys. For the street lighting loops, poles are required across the end of the block in some cases. Poles are kept off Main Street, which is the main business street, by serv-

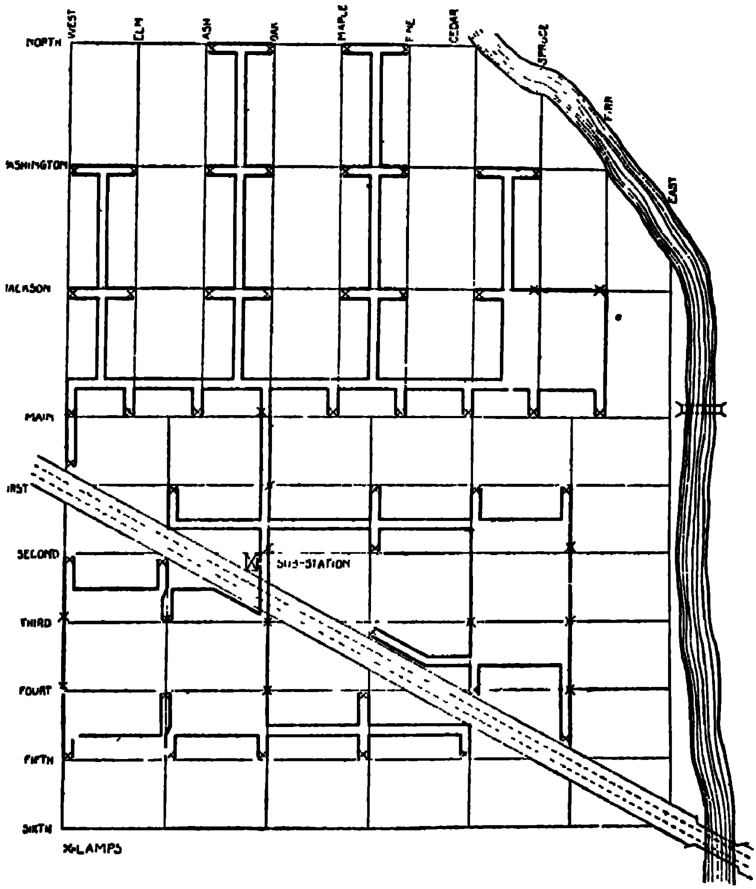


Fig. 57 Series Lighting Circuit

ing the buildings from the rear and by looping the street lamps from the alley north of Main Street.

The poles are placed as near the lot lines as possible as shown in the typical blocks in Fig. 56. This avoids interference with the use of rear gates, garages, etc., and permits the use of one pole for four service drops with a minimum amount of crossing over other property than that served.

Height of Poles. The height of the poles will vary in different parts of town, but they will be chiefly 30- or 35-foot poles with 7-inch tops. If the alley routes are also used by a telephone company, joint construction will greatly simplify matters. If joint poles are erected, they must be 35-foot poles in order to give room for the equipment of both companies and to keep the telephone equipment, which should be below, at a proper height above the ground. If joint poles are not used, the electric service poles must be at least 5 feet higher than the telephone poles in order to allow the service drops to buildings to clear the telephone wires.

If there are no telephone lines in the alleys, the electric lines can be carried on 30-foot poles in most cases. When lines cross a street, 35-foot poles are often necessary to give the required clearance over the roadway and other pole lines.

Pole Equipment. The poles should be equipped with two four-pin crossarms in the residence districts, the upper one to carry the 2200-volt main and the street lighting circuit and the lower one, the secondary three-wire main. In the alleys north and south of Main Street where some of the buildings are built back to the alley line it may be desirable to use alley arms in some of the blocks.

Where there are three or four services taken from one pole, they should be carried from a buck arm below the secondary arm. All arms should be bolted to the pole and secured by 26-inch braces of strap iron. Bolts and braces should be hot galvanized for preservation from rust.

The insulators should be the usual glass double-petticoat type.

Lightning Arresters. Lightning arresters should be provided at the substation on the 2200-volt line and in the vicinity of the larger transformers along the line. This would require about eighteen arresters as indicated on the diagram of primary lines in Fig. 55.

Grounding Transformers. The neutral wire of the secondary mains of each transformer should be well grounded. This is best done by running a ground wire from the neutral service wire to a water pipe in at least two buildings in each block. If this is not feasible, a ground may be established by driving 8 feet of

½-inch galvanized iron pipe into the ground at the base of the pole. The wire connecting to the ground should be covered by wood molding as a protection to linemen working on the pole and to the public.

RURAL DISTRIBUTION

METHODS OF GIVING RURAL SERVICE

Rural Conditions. The distribution of electricity in farming communities and in villages having less than 1000 inhabitants differs from that in cities and towns chiefly in the fact that the consumers are not grouped closely, but are separated from each other by considerable distances. This results in a rather small total load in most cases, which means small income in proportion to the investment, and this, in turn, demands that the construction be as inexpensive as possible.

In certain sections of the United States, such as the fruit districts of central California, the use of electricity is heavy owing to pumping water for irrigation; in other sections, as in the mining districts, there are many large users of power. In such cases there is so much income that a high grade of construction is justified, and the conditions are so different that they will not be classed as rural distribution.

The situations which require careful consideration are those where the farmers along a main thoroughfare and the people in a neighboring village are asking that they be given an opportunity to purchase electric service from the central station company. The district is perhaps settled with farmers well able to pay for the service, and there is an assured income from year to year if the line is constructed to serve them. The problem is to construct a line for a sum of money which will not involve fixed charges amounting to more than the income which will be derived annually from the consumers.

The problem is usually solved either by connecting the consumers from a transmission line already passing through the district or by installing a separate circuit at lower voltage. This separate circuit may be carried on the same poles as the transmission line, or a complete new line may be built.

SERVICE FROM EXISTING TRANSMISSION LINE

Lines Operating at Pressures above 15,000 Volts. If a transmission line is available, it should of course be used in case it is feasible to do so. However, where the voltage of the line is above 15,000, it is a matter of disproportionate expense to make the connections and properly safeguard the important service carried by the main line. The cost of transformers in small sizes such as are needed for farm service is high, and at 33,000 volts, for instance, transformers are not made in the smaller sizes. Furthermore the lightning arresters and disconnective switching arrangements are increasingly expensive as the voltage for which they are designed increases. It is therefore usual to limit the taps taken from lines operating at pressure above 15,000 volts to those requiring 25 kilowatts or more, which means an industrial enterprise or a town of 1000 or more inhabitants. If it is an industrial enterprise, it usually requires three-phase service, while the small town may often be served single-phase.

The equipment required for such an installation consists of a platform carried by poles or steel work, disconnective switches, lightning arresters, transformers, and metering equipment.

Transformers. The transformers being small, the installation can be isolated from the public more readily by mounting it on poles than otherwise. The larger installations, 150 kilowatts or more, are sometimes mounted on steel towers, Fig. 58. If properly galvanized and maintained, this is a more permanent and dependable form of construction than that employing wood poles, but it also requires a greater initial investment. Steel is therefore used where it is not likely that reconstruction will be necessary and where the income to be derived fully justifies the best construction.

Disconnective Switches. Disconnective switches are required for the purpose of opening the connection to the transformer on the high-tension side. These switches must be insulated for the line pressure and are arranged with handles for operation from the transformer platform or from the ground. The operating mechanism is arranged to open all wires of the circuit at the same time in the larger installations. Smaller units may be cut off by opening single-pole switches with an insulated hook. A disconnective

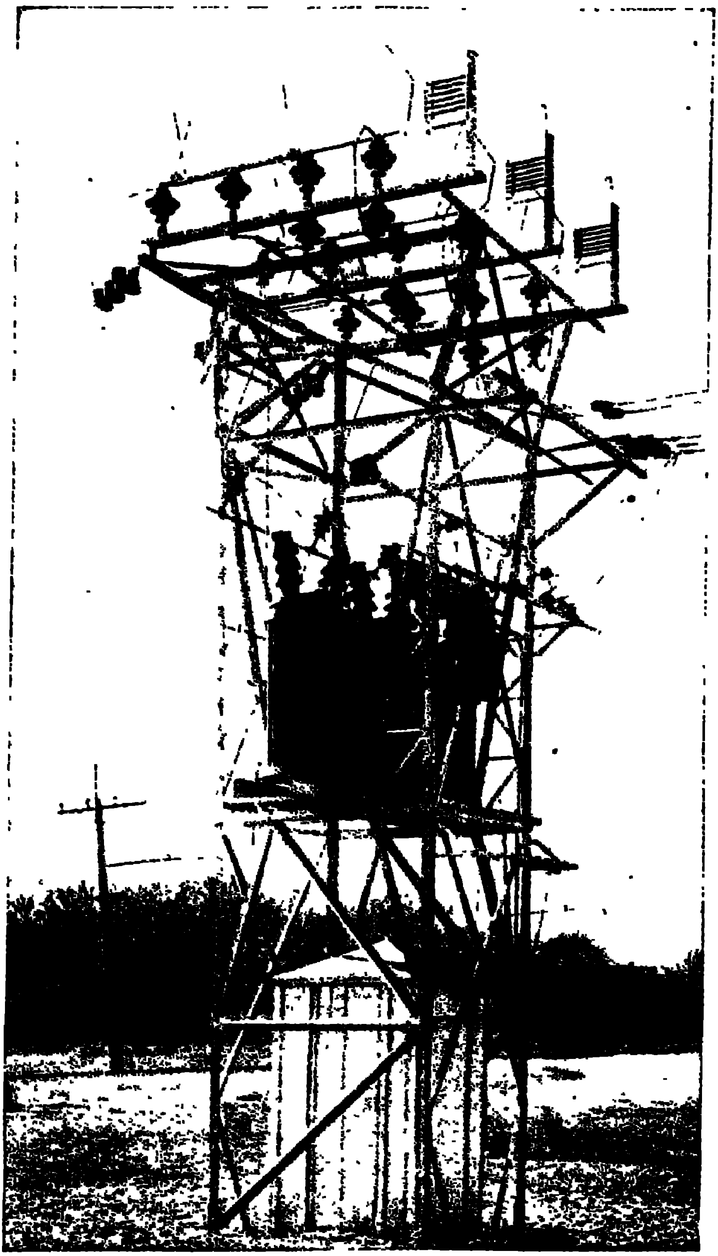


Fig. 58. Steel Transformer Platform and Arresters

switching equipment is contained in the installation shown in Fig. 58. The transformers must be provided with outdoor-type entrance bushings and otherwise designed for outdoor use.

Lightning Arresters. The lightning arrester equipment is preferably of the horn-gap type with suitable current-limiting resistance, Fig. 58. The electrolytic type of arrester is too expensive for installations such as these.

Metering Equipment. The metering equipment is preferably placed on the low-voltage side, where it is readily accessible for inspection and test.

Pressures below 15,000 Volts. With lines operating at pressures below 15,000 volts smaller installations may be used at reasonable expense, and it is not unusual to take service for farms and other individual users from such lines at any point where it may be desired. Such installations require only a lightning arrester, primary fuse, and transformer, all of which are readily mounted on a pole without a platform.

Extension to Consumer's Premises. Where the prospective user's premises are not immediately adjacent to the line, the extension from the line to the consumer's premises is usually made at the expense of the consumer, as it is for his exclusive use (or for the use of several who share the expense jointly).

Disadvantages of Method. Service from a through line in this manner may not give the users who are connected along the line a very steady pressure for lighting service as the line pressure must be regulated for a point farther away. The pressure may be too high at certain hours when the station load is greatest. This may result in excessive lamp renewals if the lamps are used during these hours, but regulating equipment for such installations is not feasible. Where conditions justify it, the most satisfactory way to serve such consumers is by a separate circuit from the nearest point of supply where such a circuit can be regulated and controlled.

SERVICE FROM SEPARATE CIRCUIT

Character of Circuit. When the conditions are such that a separate circuit must be used, the circuit may be carried on the transmission poles if there is sufficient height to permit it. In any event some of the poles may have to be replaced by higher

ones to provide clearance at crossings. The circuit will spread over a wide range as compared with circuits in town, and the voltage should be high enough to permit satisfactory service to be given. A typical circuit of this class is shown in Fig. 59.

Circuits with a pressure of 2200 volts can be extended from town two or three miles for a few consumers, but if the distance is greater, a higher voltage is necessary; a pressure of 6600 or 13,200 volts is most likely to be used if the distances are as much

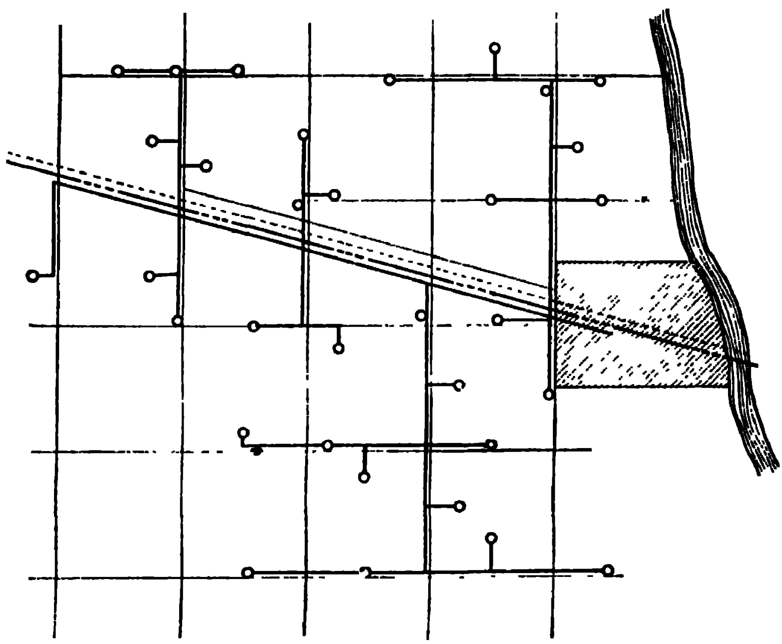


Fig. 59. Rural Distribution Lines

as five to ten miles. Where there is enough power to require a three-phase circuit, the three-phase four-wire system with 4400 volts between phase wire and neutral or 7600 volts between phase wires is found very useful. This permits the use of standard 4400-volt transformers, which are made in all standard sizes of 2200-volt units, and also makes it possible to regulate the pressure on each phase separately, thus giving better lighting service than is possible with a three-phase three-wire circuit or a single-phase circuit.

Equipment. In distribution by separate circuits at voltages of less than 10,000 the fuses and arresters are not an item of great expense relatively, and disconnective switches are needed only for sectionalizing portions of the line while working on it. The line work may also be of a simple character, differing from that required for 2200-volt lines chiefly in the style of insulators employed.

Advantages of Method. The cost of each installation is so much on the higher voltage lines that it is cheaper to run a separate circuit on the same poles if there are to be any considerable number of consumers. Furthermore, if some of the consumers have to be reached by branches from the main line, the addition of such taps introduces an element of risk to the service on the main line which may be very undesirable.

CONSTRUCTION DETAILS

Character of Lines. The necessity for installing the plant with the lowest investment practicable and the fact that the lines are in rural communities modify the type of construction in some particulars. The lines consist chiefly of poles and primary wires, since there is but very little secondary distribution, a separate transformer being required at each farm.

POLES

Height of Poles. The pole equipment can be limited to a single crossarm, two-pin where single-phase or four-pin where three-phase. This in turn permits the use of shorter poles, 25-foot poles giving a clearance of about 18 feet above ground at the point of lowest sag in the wires with 150-foot spans. The clearance at road crossings must usually be about 21 feet, and higher poles are necessary at these points. Spans of 200 to 250 feet are sometimes used, but this requires stronger and higher poles, 30 feet being the minimum pole length to give a clearance of 18 feet at the lowest point of the span.

Size of Poles. With poles set at 150 feet the top diameter may be 6 inches, but with longer spans 7-inch tops should be used. At corners or bends a 7-inch top pole is desirable, unless the strain may be fully carried by guys. Poles having tops as small

as 5 inches are sometimes used for branch lines. However, the butts of such poles are so small that the life of the pole at the ground line is short, and the larger diameter is cheaper in the end.

Where a line is exposed to high winds, as in going over a hilltop, it is well to provide extra strength either in the poles or by means of side guys or braces. Poles carrying a transformer installation should have 7-inch tops at least, and if the installation is over 10 kilowatts, it will be more durable on an 8-inch pole.

WIRE

Methods of Reducing Cost of Wire. The wire being the next largest item after the poles in the cost of a line, much attention has been devoted to methods by which this part of the investment may be reduced to a minimum. The first step is naturally the use of bare wire, as insulation is not needed in the open country. The next step is to reduce the size to a point as low as the joint requirements of voltage drop and mechanical strength will permit. With line voltages above 5000 at the small loads usually found it is the mechanical strength which fixes the final limit of size. For this reason it is often possible to use iron or steel wire as a conductor without sacrificing too much in the way of voltage drop.

With copper conductors the smallest size which is dependable in soft wire is No. 6, but with hard-drawn wire the line may safely be made as small as No. 8. With the smaller conductor the wind pressure is reduced and longer spans can be used. Because of the lower cost of iron or steel wire, its use makes it possible to construct lines which it would be unprofitable to build if copper were used. Copper-clad steel wire is also used for this purpose, the coating of copper serving the double purpose of protecting the steel from corrosion and improving the conductivity.

Sizes of Iron and Steel Wire. The two kinds of iron wire commonly sold are known as B.B. and E.B.B. and are drawn by the numbers of the steel wire gage. No. 4 is the largest size ordinarily used in solid wire. Steel wire is also drawn in the same sizes. Seven-strand cable is used in the larger sizes, and they are rated as $\frac{1}{4}$, $\frac{5}{16}$, $\frac{3}{8}$, and $\frac{1}{2}$ inch in diameter. All such wires and cables should be galvanized unless copper clad.

Limitations on Use of Iron or Steel Wire. The use of iron or steel wire is, however, subject to limitations which should be well understood and kept in mind in determining the kind of conductor to be used in particular cases. The current density cannot be over about 1 ampere per 10,000 circular mils, or one-tenth that of

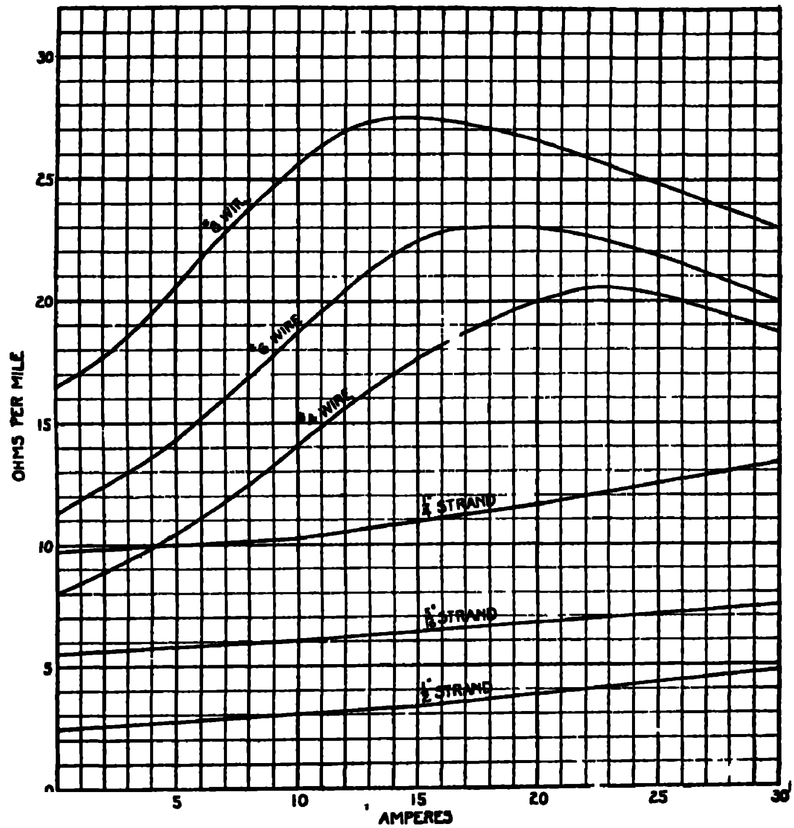


Fig. 60. Relation of Resistance to Current Strength in Steel Wire

copper wire. If higher current densities are used, the loss is excessive and the voltage variation troublesome.

The electrical resistance of iron and steel depends largely on its composition and heat treatment during manufacture, and it varies further with the strength of current flowing in the conductor. In Fig. 60 the relation between resistance and current for solid steel wires and cables is shown. The resistance of No. 4 steel wire, for instance, increases from 8 ohms per mile at 1

ampere to 20.5 ohms at 22 amperes and then decreases to 18.5 ohms at 30 amperes. The variation is not so wide in stranded conductors, it being from 9.75 ohms per mile at 1 ampere to about 13 ohms per mile at 30 amperes in the case of a ½-inch cable. The resistance of iron B.B. and E.B.B. wire varies more widely with the current than does that of steel wire. It is therefore not feasible to have a table of resistances such as that for copper wire, which is constant except for temperature variations.

The variation in resistance in iron and steel is due to their magnetic properties, which with alternating current set up internal currents; these, in turn, as the current strength varies produce an effect equivalent to a change in resistance.

The inductive reactance of iron and steel wire is more than that of nonmagnetic conductors, but the ratio of resistance to inductance is so much greater for iron and steel wire than for copper wire of equal size that the reactance does not affect the line drop very much.

The field for the use of iron and steel wire and its limitations may be best seen from a few examples such as would be ordinarily met in practice:

Examples. 1. With a load of 22 kilovolt-amperes at 6600 volts, single-phase, at a distance averaging 5 miles from the point of supply, what will be the loss with steel wire? The current C on the circuit is $\frac{22000}{6600}$, or 3.33 amperes. According to Fig. 60 the resistance R of No. 6 steel wire at 3.33 amperes is 13 ohms per mile of wire. There being 2×5, or 10 miles, of wire in the single-phase circuit, the total resistance is 10×13, or 130 ohms. The loss E is

$$E=CR=3.33\times130=433 \text{ volts}$$

$$\text{which is } \frac{433}{6600}, \text{ or } 6.5 \text{ per cent}$$

This would permit reasonably satisfactory lighting, assuming a steady source of supply.

The cost of the wire for the No. 6 steel circuit at \$5.00 per 1000 feet is $2\times5.28\times5.00$, or \$52.80 per mile of circuit. With a No. 8 hard-drawn copper circuit the cost at 15 cents per pound is $50\times5.28\times2\times\$0.15$, or \$79.20 per mile of circuit. Thus it would be economical to use steel wire for such a load at 6600 volts at a distance of 5 miles. However, for a larger load a larger steel wire would be needed, and the advantage would be lost for a load above 30 kilowatts under these conditions. With 13,200 volts a load of 80 kilowatts could be carried five miles or a load of 45 kilowatts, 10 miles with the same loss of 6.5 per cent on No. 6 wire.

2. With a three-phase circuit, carrying a load of 150 kilovolt-amperes at a distance of 10 miles and a voltage of 13,200, what will be the loss if steel wire is used? The current is $\frac{150000\times 1.73}{3\times 13200}$, or 6.57 amperes. At 6.57 amperes with No. 4 steel wire the resistance R is 10.7 ohms per mile per wire, or 107 ohms for 10 miles

$$E=6.57\times 107\times 1.73=1210 \text{ volts}$$

which is 9.2 per cent.

With No. 8 copper wire the resistance is 10×3.32, or 33.2 ohms per wire and the loss is

$$E=33.2\times 6.57\times 1.73=378 \text{ volts}$$

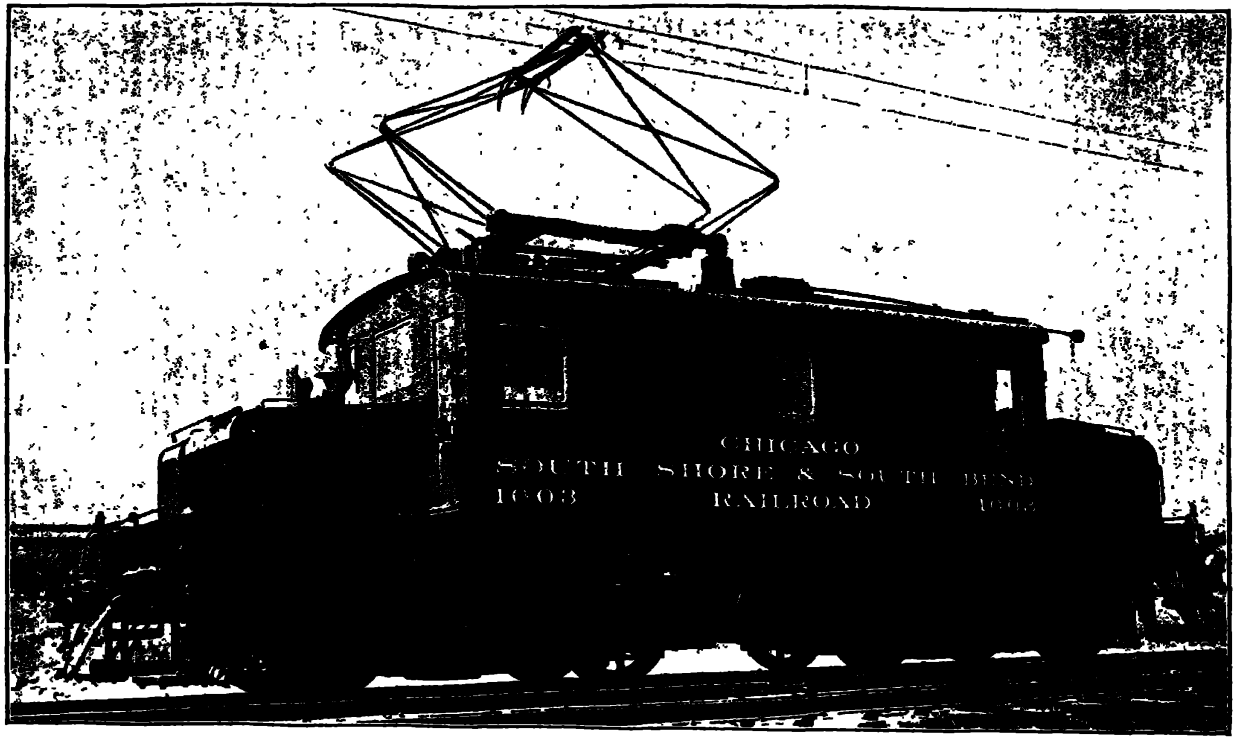
which is 2.9 per cent.

The cost of a No. 4 steel circuit at $7.00 per 1000 feet is 3×5.28×$7.00, or $111.00 per mile of circuit. The cost of a No. 8 copper circuit at 15 cents per pound is 3×5.28×50×$0.15, or $119.00 per mile.

As the loss with a No. 8 copper circuit is but 31 per cent of that with a No. 4 steel circuit and the cost is practically the same, there is little advantage in the use of steel under the conditions assumed.

Factors Effecting Choice of Copper or of Iron or Steel. In general, there is an advantage in the use of steel only when the load is small and the distance short in proportion to the voltage, so that the minimum size of copper which can be used for mechanical strength is several times as large as is necessary for proper voltage regulation. This condition is, of course, met much sooner when the price of copper is high than when it is at its normal price of 15 to 20 cents per pound.

Where there is a prospect of rapid growth, the use of copper may prove most economical in the end, as the cost of replacing the wire and the disturbance to the service may well be enough to offset the saving of a few years' interest on the additional investment. It should also be borne in mind that when electric service is once available, there are additional uses found for it each year, and these often result in a growth of load which is unexpectedly large.



ELECTRIC LOCOMOTIVE FOR HEAVY INTERURBAN SERVICE—1600 HORSEPOWER
Courtesy of Westinghouse Electric and Manufacturing Company

ELECTRIC RAILWAYS

PART I

Purpose of Electric Railways. Before a student can appreciate the functions of the different parts of an electric-railway system, he must know what the primary purpose of such a system is, as the details of selection and operation of equipment must have a direct bearing upon this purpose. The following important statement therefore should be kept in mind throughout the course:

The purpose of a railway system is to transport paying load between points at minimum total cost with maximum safety.

A railway is termed in law a "common carrier," and as such it enjoys privileges not common to other lines of business, such as the use of streets and roads, and is more or less of a monopoly in its territory. For this reason it is subject to the control of the public to a greater extent, and this fact affects the engineering problems and the details of equipment. For example, the state commissions which control railway operation and equipment—subject, of course, to the jurisdiction of the courts—may specify details of equipment which the company might not choose on the basis of economy, which fact must be kept in mind in connection with the previous statement of the purpose of a railway.

The two electric-railway problems, namely, street and interurban transportation, must not be confused with heavy electric railroading. The latter, although very important, does not affect the average man engaged in electric-railway work. It is largely a matter of replacing steam with electric locomotives. This subject is treated in the text, "Steam Railway Electrification."

Engineering Features. From the engineering standpoint the problems of railway operation are largely problems of mechanics. A car loaded with passengers or freight is simply a mass which has to be brought from rest up to speed; maintained at speed for a while; and brought to rest again. That is all there is to the mechanical problem, but this series of three operations involves a vast amount of detail in electric-railway practice. The present

study is designed to familiarize the student with this detail as systematically and simply as possible. He will be assisted in his study by noting the divisions of a modern railway system, namely:

(1) Rolling stock, including equipment
(2) Motive power (power houses and substations)
(3) Maintenance of way (track)
(4) Transmission
(5) Transportation (time-tables and crews)
(6) Administration and business

These departments may or may not include the necessary engineering and construction forces necessary to build, to renew, or to extend the plant. The course will consist in descriptions of the equipment necessary or desirable and of the principal practical and theoretical features involved. The major portion of the space has been allotted to the first division; the student is already partly familiar with the railway power station from his earlier studies.

ROLLING STOCK AND EQUIPMENT

Historical. Before describing the apparatus it may be well to call attention to the history of the development of the modern car, which has come, through a process of evolution, to perform its functions so perfectly. It has always been the case that every new form of motive power has been applied first, or at least very early, to transportation. The reason for this is that transportation furnishes the largest single field for the application of power. As soon, therefore, as the electric motor gave promise of commercial success, even when current had to be obtained from primary batteries, experiments were begun with a view to producing electric cars. In 1834 Thomas Davenport, a blacksmith of Brandon, Vermont, made a small model of an electric car. This was, of course, driven by primary batteries, for a satisfactory form of the electric generator, or dynamo, was not produced until many years later. Davenport made his own motors, which consisted of permanent magnets and electromagnets, and these, by their attraction, produced the torque. One of the successful motors of this time was that of a Russian, M. H. Jacobi. His motor was applied to a car by Robert Davidson of Aberdeen, Scotland, about 1838. An idea of the principle of this motor can

be obtained from Fig. 1, which shows a motor used by Jacobi in a boat on the River Neva, Russia, about this time. There are two sets of horseshoe electromagnets held in stationary frames facing each other and with a space in between; these are the field magnets. Between them is the revolving armature consisting of bar electromagnets, one bridging across each pair of opposite field poles. Current flows to the armature through collectors and brushes by means of which the current is applied intermittently. The magnets give a series of jerks upon the armature and thus keep it revolving. While this motor produced considerable power, it was not efficient.

In this country in 1847 Prof. Moses G. Farmer made a car with a motor which looked like a "Ferris wheel," only that iron armatures which were attracted by electromagnets took the place of the cars. The principle was not substantially different from that of Jacobi's motor. It is not necessary to mention all the early attempts at electric traction, for, until a good source of electric power was devised, all of these attempts were commercial failures.

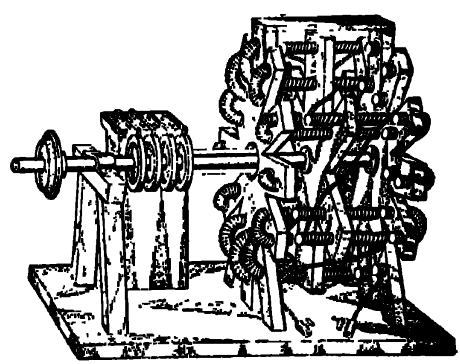


Fig. 1 Early Jacobi Motor Used on Boat in Russia

It was in 1879 at the exposition at Berlin, Germany, that a successful car was shown and operated, drawing a number of trailers filled with passengers. The car was simply a Siemens motor laid on its side on a little truck and geared to the wheels. Current was taken in from the rails. The firm of Siemens & Halske, now so well known in the electrical business, put a regular car into operation in the suburbs of Berlin in 1881. In this country from 1880 to 1885 there were many experimenters trying to make electric cars, particularly locomotives. The names of Stephen D. Field, Thomas A. Edison, Frank J. Sprague, Charles J. Van de Poele, Leo Daft, Sydney H. Short, and others should be familiar to every student of electric traction. Finally in 1887 the first

large equipment of electric traction in this country was installed by F. J. Sprague in Richmond, Virginia, and within a few years the horse, cable, and steam cars disappeared from the streets.

The essential parts of a car are the car body and trucks; the motors and controlling apparatus necessary in starting the car and keeping it going; the braking apparatus for bringing it to rest; and sundry current-collecting, protective, heating, and other secondary equipment.

CAR BODY

Requirements. The essential features of a properly built electric car are: (1) *mechanical strength*, to stand the strains incident to starting and stopping, to irregularities of track, to rounding curves, to collisions, to carrying heavy loads, etc.; (2) *light weight*, to avoid loss of power resulting from hauling around unnecessary dead weight; (3) *accessibility*, to ensure safe and at the same time rapid loading and discharging of passengers; (4) *convenience*, so that the comfort of passengers is well cared for in regard to seating, lighting, heating, and ventilation; and (5) *attractive appearance*, to please the riding public and thus attract business.

Classification. In general, electric cars may be divided into three classes: light-weight single-truck cars; double-truck city cars; and high-speed interurban cars. In addition to these well-defined groups, there are many special types used for special conditions including subway and elevated types and cars for electrified steam roads.

The so-called light-weight safety car has become very popular on account of the saving in wages, reduced cost of maintenance, and lower power costs.

Double-truck city cars, Fig. 2, are used where the traffic is too heavy for small cars and are designed for moderate speeds and frequent-stop service.

High-speed interurban cars, Fig. 3, are of necessity more strongly constructed, which means greater weight to withstand the strains incident to speeds of 60 miles per hour or even higher.

Construction. The tendency in all types is toward the increased use of steel construction, ranging from a steel frame in the small cars to an all-steel construction in the high-speed interurban and suburban types.

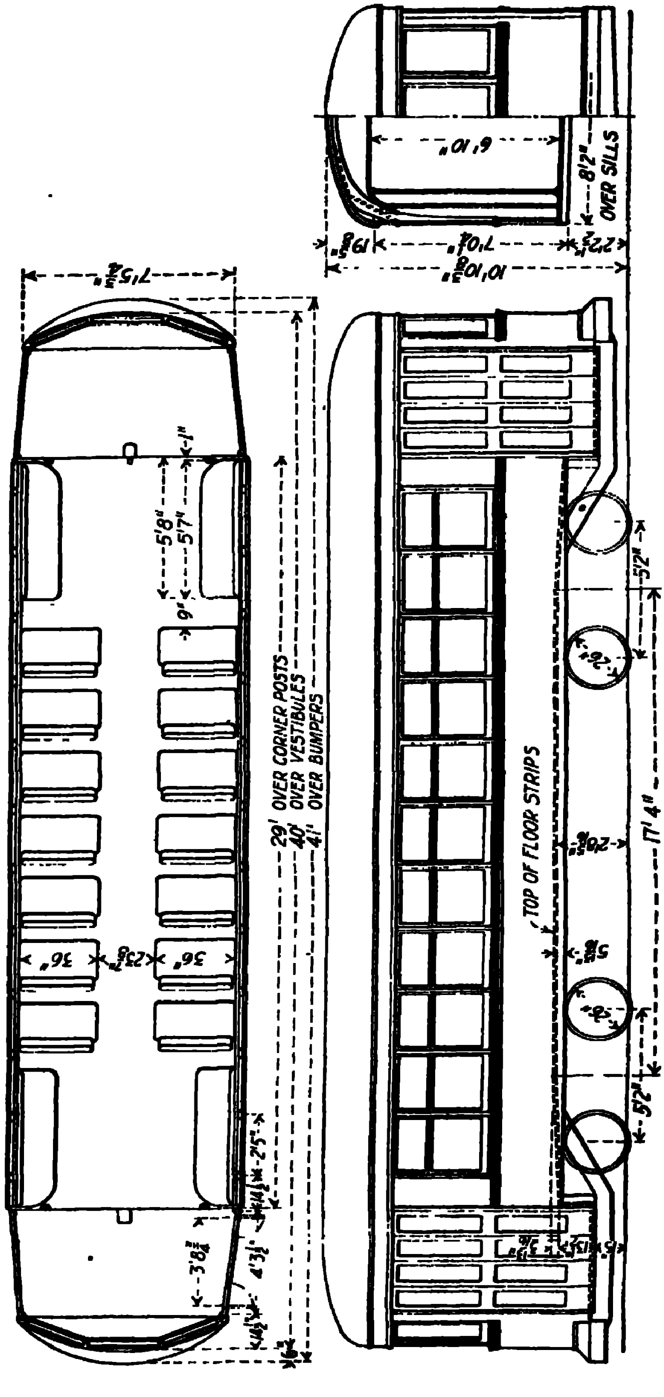


Fig. 2. Plan, Elevation and End Section of Double-Truck City Car

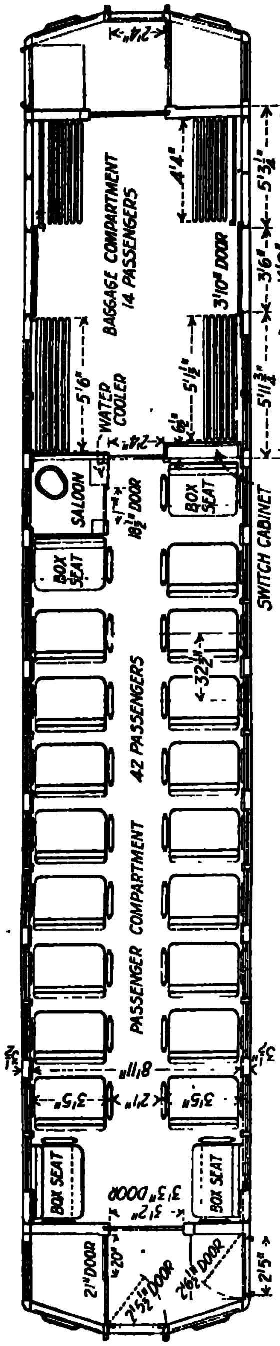


Fig. 3. Seating Plan of Typical High-Speed Interurban Car

As a matter of economy in construction, an arch roof is commonly used, with suitable ventilating openings. Platforms and vestibules and, on some types, a center door are provided to expeditiously handle passengers and to assist in taking up fares, as well as to accommodate the crew and the controlling apparatus. The important divisions of the car body are: underframe and floor; sides and ends; roof; and platforms, vestibules, and doors.

Double-Truck City Car. *Frame.* The underframe is the foundation of the body and its design and construction are therefore of greatest importance. The frame is most commonly an all-steel structure composed of side, center, intermediate, cross, and end sills of heavy angle and bracing. A typical city car of the double-truck type is shown in elevation plan and section in Fig. 2. The side, center, and end sills are designed for strength and stiffness to withstand buffing strains and may be either of wood, steel, or a combination of both. The center sill is a steel I beam, 6 inches deep at the center with a wood filling bolted securely to both sides. The side sills in this case are $5'' \times 3\frac{1}{2}'' \times \frac{5}{16}''$ angle reinforced at the bolsters with angle of the same dimensions. Z-shaped end sills of $\frac{3}{16}$-inch pressed steel are securely bolted to side sills and platform knees; the crossings are of $\frac{1}{8}$-inch pressed steel attached to the side sills by angle brackets. This construction is shown in detail in Fig. 4.

The bolsters are of cast steel bolted to the side sills with openings for the passage of brake rods, conduit, etc. The outside platform knees are of 7″×3½″×⅜″ angle reinforced with 2″×2″×⅜″ angle under the end sill. These outside platform knees, Fig. 5,

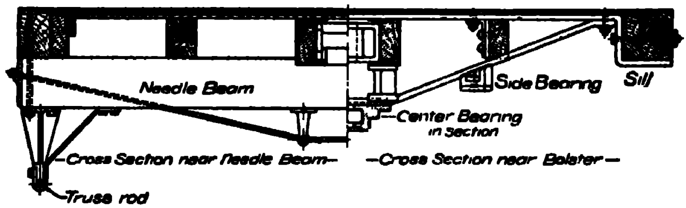


Fig 4 Cross-Section of Underframe Showing Needle Beam and Bolster

are suspended on the pressed-steel end sill, the knee bearing directly under the side sill at the end rear.

Body. In the body framing of the car the side posts are of 2″×2″×¼″ and 2″×2″×$\frac{5}{16}$″ tees extending from the side sills to the top rails. The corner posts are of $\frac{3}{32}$-inch steel, and the side sheathing is of the same dimension made in three sections. The roof is of the plain arch type running the full length of the car supported on U-shaped pressed-steel rafters. Figs. 6 and 7 show the steel frame in process of erection.

High-Speed Interurban Car. For purposes of illustration, description is here given of a typical high-speed interurban car of all-steel construction arranged with both a passenger and a baggage compartment, Fig. 3. The passenger compartment is 31½ feet long, seating forty-two passengers, and the baggage compartment is 14 feet 4 inches long with folding seats for the accommodation of fourteen additional passengers. The weight of the car

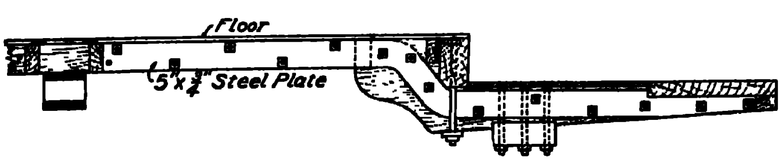


Fig. 5. Platform Knee

body without electrical equipment is 36,500 pounds, and the total weight of the car completely equipped is 41 tons.

The construction throughout is somewhat heavier than the city-type car just described, as is easily shown by the difference

in weight, the city car weighing about 15 tons with a seating capacity of forty-four, while the interurban car weighs 41 tons

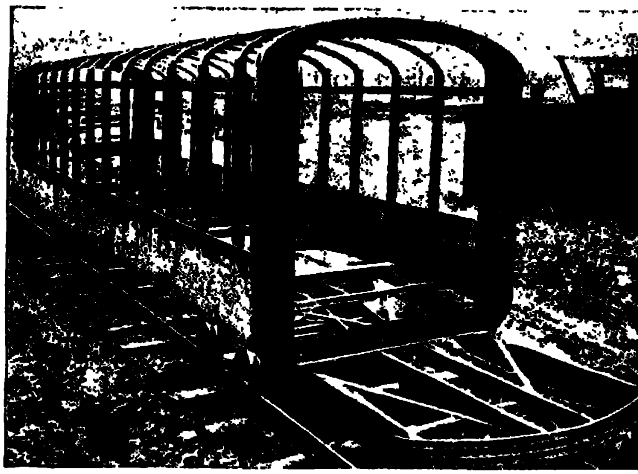


Fig. 6. Superstructure Framing of Steel-Frame Car

with a seating capacity of fifty-six including space in the baggage compartment.

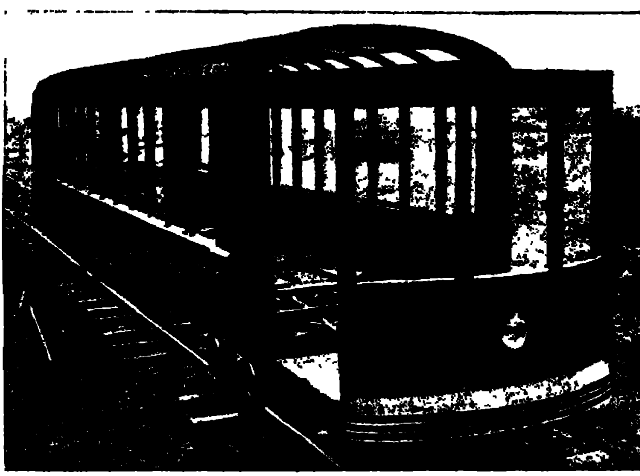


Fig. 7. Framing Complete, Ready for Roof Sheathing and Wood Floor

Vestibules. For city service the prepayment system of fare collection has been almost universally adopted. With this

improvement has come the fully enclosed platform with folding doors and steps to eliminate accidents due to boarding or alighting from moving cars. In many cases the construction of the car is modified to include center entrance or exit for the purpose of more rapidly loading and unloading the passengers. The platform is usually made of sufficient length to allow passengers to get on and off at the same time. Some form of the pay-as-you-enter plan has been adopted for practically all city service. Fig. 8 shows a typical platform divided into two sections by a guard rail. The larger section *B* is for entering passengers, and *C* is an exit passageway. Space is also allotted for the conductor, from which he can collect fares, operate doors, etc. The front platform is intended as the main exit and, in the case of single-end cars, can be made shorter than the rear vestibule. The motorman is so located that he is out of the way of passengers and is preferably protected by a guard rail to prevent interference in case of crowded cars.

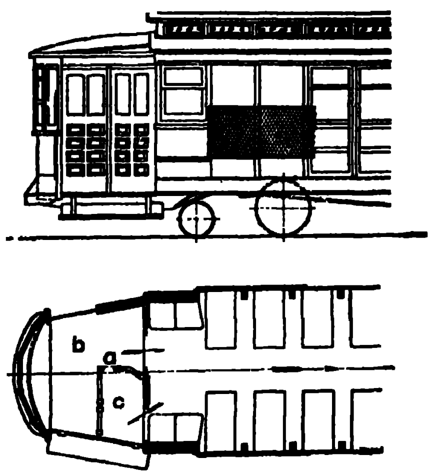


Fig. 8 Pay-As-You-Enter Car

One of the important modifications of the pay-as-you-enter type is the so-called Peter Witt car, in which the passengers enter at the front end and pay upon passing the conductor at the center of the car. The object of this arrangement is to allow such passengers as wish to pay immediately to pass to the rear of the car, while others who may wish to pay later can remain in the front half of the car. This facilitates the payment of fares by distributing the time of payment over a longer period and is especially useful at terminals where practically the entire car is filled at once.

TRUCKS

Classification. The electric car body is carried on trucks, each truck having four wheels. There may be either one or two

trucks per car, which is indicated by the terms "single-truck car" and "double-truck car." The construction of single and double trucks is quite different and will be treated separately.

Single Truck. A typical truck for a light-weight city car is shown in Fig. 9. In this truck the wheels are 24 inches in diameter with a wheel base of 8 feet. There are two longitudinal steel strips, *A* and *B*, to which the car body is bolted. Each of these strips is supported on two leaf springs S_1 and four coiled springs S_2. The coiled springs take the main weight of the body, while the leaf springs support the ends of the body which overhang the axles. Both the coil and leaf springs rest upon a forged side frame *F*, which is spring supported by means of the springs S_3. These springs rest in the sockets of steps, which project from the bottom of the journal boxes *J*. The journal boxes are of cast iron and carry the bearings and afford space for lubricating grease or

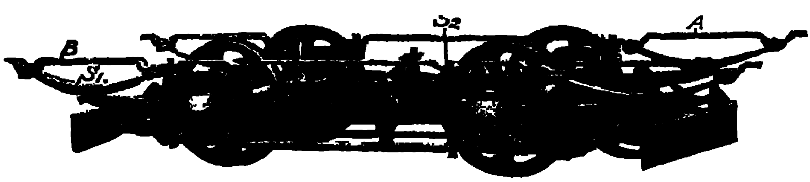


Fig. 9 Brill Single Truck

oil. Where the side frame passes over the journal boxes, it is arched so as to clear them. The sides of this arch form guides which work in groups in the sides of the journal boxes. The frame can, therefore, move up and down as the springs are compressed, but its motion in other directions is restrained. The journal boxes, carrying the weight of all the parts so far described as well as that of the car body, rest upon the ends of the axles. The journals, the wearing parts of the axles, project beyond the wheels, which are pressed upon the axles.

In addition to the essential features mentioned, the truck illustrated in Fig. 9 contains several important details, which may be seen in the figure. The two side frames are held in the proper position by braces at the center and by the "pilot boards" *O* at the ends. The motor-suspension bars *M* are spring supported from the side frame. These bars are provided to carry a

part of the weight of the motor, the balance of which is supported by the axles. The brake rigging, comprising shoes, hangers, rods, and levers, is carried by the truck. This is not shown clearly in the illustration and will, with the other details, be described separately.

The purpose of the rather elaborate spring support of the car body and truck frame is to provide comfortable riding for the passengers and durability for the car and the track. When the wheels strike irregularities in the rails or obstructions upon them, the wheels are given a violent upward or downward motion. This motion is not communicated instantly and violently to the car body, which possesses inertia, but it is more or less absorbed by the springs. The car is thus relieved of the blow which it would otherwise receive, and in turn the track is saved the reac-

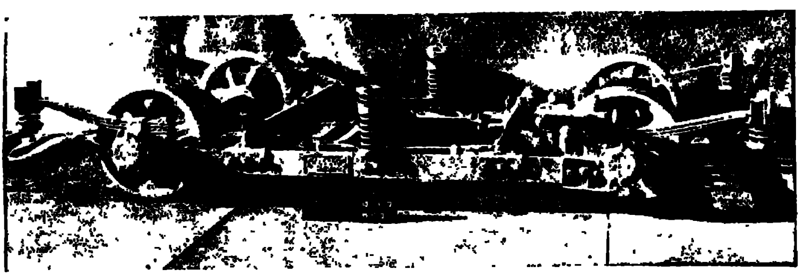


Fig. 10. Brill Standard Light-Weight Truck

tive blow due to the mass of the car. The spring system is designed to prevent *teetering* of the body while giving as much flexibility as possible. Teetering, as the name indicates, is the backward and forward vibration of the body, which is started and maintained by irregularities in the track. It is very trying to the passengers. The leaf springs S_1 tend to prevent this trouble.

A single truck of somewhat different construction is shown in Fig. 10. The general arrangement of the parts is given in the illustration, and it will be noted that the wheels are equipped with ball bearings. The wheels are 24 inches in diameter, and the entire truck weighs only 3300 pounds.

Double Truck. *M.C.B. Truck.* There are several common forms of double trucks, including what are known as M.C.B. trucks, which are built on lines recommended by the Master Car

Builders' Association for steam railroad equipment. Two such trucks are used per car where the bodies are too long for a single truck of the type previously described. These are known as

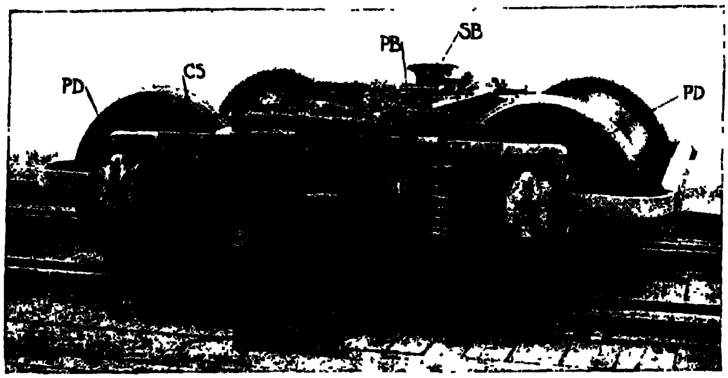


Fig. 11. Brill M C B. Truck

swivel trucks and have the advantage of a short wheel base, that is, short distances between axle centers, which construction permits them to pass easily around the sharp curves used in many city streets. From Fig. 11 it will be seen that the truck consists of a rectangular steel frame, supported by coiled springs which rest on equalizing bars, or yokes, extending from journal box to journal box on each side, distributing the weight equally to

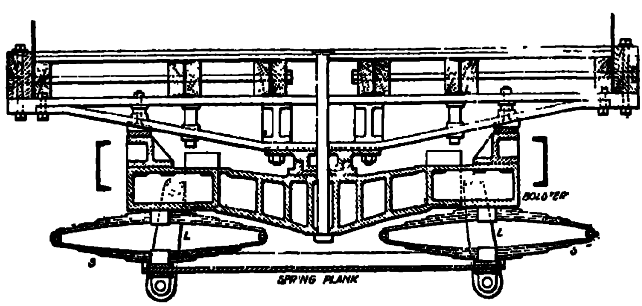


Fig. 12. Section of Bolster, Elliptical Springs, and Spring Plank

both axles. The car body is supported on a center pivot plate upon which the truck turns, or swivels. The bolster of the car body rests upon this bearing plate and is held in place by a king

bolt to prevent the pivot plate becoming unseated. The pivot plates form the main supports of the car body, which is balanced sidewise upon them when the weight is evenly distributed. Side bearings are also provided to prevent the car tipping when the weight is unbalanced, in which case they rub on the side bearings of the car-body bolster. The relative positions of the car-body and truck bolsters and the center and side bearings, as well as other important details, are shown in Fig. 12.

In order to secure the greatest possible elasticity of car-body support, a double spring system is used in the M.C.B. truck as follows:

(1) The truck bolster is carried upon a spring plank, Fig. 12, through elliptical leaf springs *SS*. Fig. 13 shows the bolster, spring plank, and elliptical springs in more detail. The spring plank hangs from the transom by links *LL*, Fig. 12, which allows a slight swing sidewise. The transom consists of two steel plates, separated by enough space to accommodate the bolster

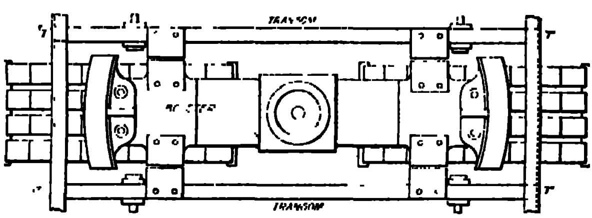


Fig. 13 Plan of Bolster and Spring Plank

and with enough clearance to permit the bolster to move up and down as the elliptical springs are compressed or released. The transom is rigidly attached to the frame.

(2) The main frame is spring supported through the coiled springs *CS*, Fig. 11, upon the side bars *D*, which in turn are carried by the journal boxes.

In order to preserve the proper alignment of the journal boxes and truck frame, the latter carries downward-projecting castings *PD*, which form guides for the journal boxes. The latter, as in single trucks, are grooved on the sides to fit the castings. These castings form the pedestal.

Of considerable importance are the small springs (not shown) on the ends of the truck bolster, which prevent it from striking violently against the truck frame; the brake hanger *BH*, which supports the brake shoe; and the pilot board, which is intended to remove obstructions from the track (see Fig. 16).

A lighter truck with a short wheel base is shown in Fig. 14. The essential parts are the same as in the truck shown in Fig. 11

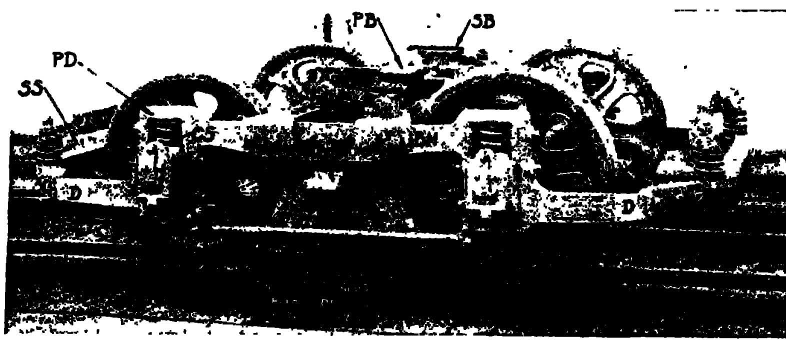


Fig. 14. Brill 51-El Truck
CS, Coiled Springs; D, Side Frame; SB, Side Bearing; MS, End Frame, PD, Journal Box Guides, SS, Motor Suspension Springs; B, Bolster Spring; P, Pedestal Tie Bar; BH, Brake Hanger; PB, Center Pivot Plate

Other Types of Short-Wheel-Base Trucks. A short-wheel-base truck of somewhat different construction is illustrated in Fig. 15. It is necessary to have a short wheel base, or distance between axle centers, when the truck has to round curves of short radius. In such a truck there is not room for the motors between the axles, and consequently the motors must be turned around with

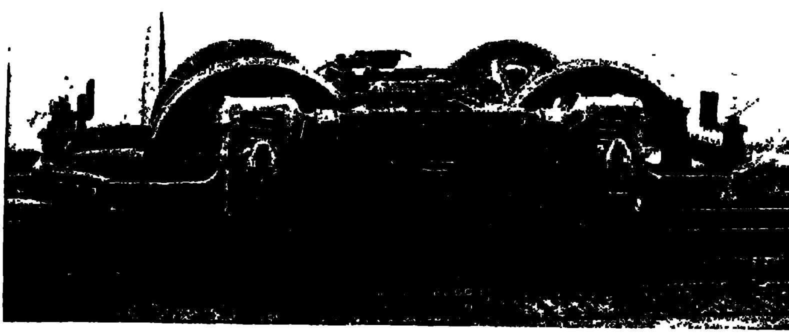


Fig. 15. Brill Short-Wheel-Base Truck with Outside-Hung Motors

their spring suspensions on the outside. Motors so mounted are *outside hung* as contrasted with the others, which are, therefore, *inside hung*. The short-wheel-base truck shown in the illustration

has some other features which are different from the other trucks described. The side bar is a steel casting which is very simple in construction. The spring support is also much simpler than in the M.C.B. truck, although it is a less easy-riding support. On the top of each journal box is a coiled spring which rests in a socket cast for the purpose. The side bar expands into a socket at the top to receive the coiled spring. The bolster is supported on elliptical springs carried by the spring plank, as in the other trucks described.

Maximum-Traction Truck. The maximum-traction truck is a special form of truck employed when two motors are to be used on a double-truck car. If but one motor is mounted on a stand-

Fig. 16. Brill Maximum-Traction Truck

ard truck, but one-half the weight of the car is available for producing adhesion between the wheels and the track when the car is being driven by the motors. In the maximum-traction truck the center of support is shifted from the center to a point as nearly over the motor axle as possible, Fig. 16. The two pairs of wheels are of different diameters, the driving wheels being of as large diameter as the room under the body permits. The others are pony wheels which follow the curvature of the track with great precision. The motor is outside hung from the main axle, as in the case of the short-wheel-base truck. In the type of truck shown the bolster is mounted on leaf springs hung from the side bar by links, this being necessary in order to allow space for the brake rigging between the wheels. The essential

features of the maximum-traction truck are the same as in the trucks described earlier. In the side elevation of a car body, Fig. 8, the wheels of a maximum-traction truck are shown.

TRUCK DETAILS

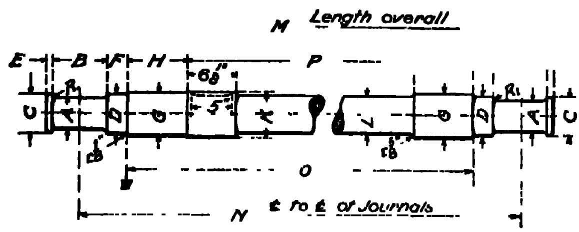
Standardized Parts. The forms and dimensions of a number of the component parts of trucks have become standardized through the co-operation of the American Electric Railway Engineering Association, the manufacturers, and the electric-railway operators. The standards adopted by the Railway Association may be considered as the best that can be devised at present. These standards were adopted by the Association in 1915. The truck parts standardized are (1) axles, journals, journal bearings, and journal boxes; (2) brake shoes, brake-shoe heads, and keys; and (3) section of tread and flange of wheel.

Axles. The forms and dimensions of axles as adopted by the Association are given in Table I. The accompanying diagram shows the different parts of an axle. At the ends of the axles are the journals *AA*, which are supported in the bearings carried in the journal boxes. Next to the journals are the wheel seats *GG*, upon which the wheels, bored slightly smaller than the axles, are firmly pressed. Slightly larger than the wheel seats is the gear seat. The gear wheel, through which the driving force from the motor is transmitted to the axle, is fitted tightly to this part of the axle. It is prevented from rotating on the axle by a steel key, which is driven into a slot and into a similar slot in the hub of the gear wheel registering with the axle slot. The remainder of the axle is available for the support of the motor, which hangs upon it by means of two bearings. At the ends of the journals the axle is enlarged to form two shoulders which prevent endwise motion of the axle in the bearings.

Specifications. On account of the importance of the quality of steel used in the manufacture of axles for electric motor cars, the American Electric Railway Engineering Association has adopted standard specifications for steel axles, this information being incorporated in the engineering manual of the Association. The following extracts from the standard specifications indicate the importance of using high-grade material for axles, shafts, and similar parts:

TABLE I

Specifications for American Electric Railway Engineering Association Standard Axles



Journal A	Journal B	C	D	E	F	G	H	K	L	M	N	O	P	R	R_1	Maximum Capacity (lb)
$3\frac{1}{4}$	6	$3\frac{7}{8}$	$3\frac{7}{8}$	$\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{15}{16}$	$10\frac{5}{16}$	4	$3\frac{1}{2}$	$76\frac{1}{4}$	$69\frac{1}{4}$	$58\frac{1}{4}$	48	$\frac{1}{8}$	$\frac{1}{2}$	9000
$3\frac{1}{4}$	6	$3\frac{7}{8}$	$3\frac{7}{8}$	$\frac{1}{2}$	$2\frac{1}{2}$	$4\frac{7}{16}$	$10\frac{5}{16}$	$4\frac{1}{2}$	4	$76\frac{1}{4}$	$69\frac{1}{4}$	$58\frac{1}{4}$	48	$\frac{1}{8}$	$\frac{1}{2}$	13000
$3\frac{3}{4}$	7	$4\frac{3}{4}$	$4\frac{3}{4}$	$\frac{5}{8}$	$2\frac{1}{2}$	$4\frac{15}{16}$	$4\frac{5}{8}$	5	$4\frac{1}{2}$	$77\frac{1}{2}$	$69\frac{1}{4}$	$57\frac{1}{4}$	48	$\frac{1}{8}$	$\frac{1}{2}$	16000
$4\frac{1}{4}$	8	$5\frac{1}{4}$	$5\frac{1}{4}$	$\frac{5}{8}$	$2\frac{1}{2}$	$5\frac{13}{16}$	$7\frac{1}{2}$	6	5	$84\frac{1}{4}$	75	63	48	$\frac{1}{8}$	$\frac{5}{8}$	18000
$4\frac{1}{4}$	8	$5\frac{1}{4}$	$5\frac{1}{4}$	$\frac{5}{8}$	2	$5\frac{15}{16}$	$7\frac{1}{2}$	6	$5\frac{1}{2}$	$84\frac{1}{4}$	75	63	48	$\frac{1}{8}$	$\frac{5}{8}$	22000
5	9	$6\frac{1}{8}$	$6\frac{1}{8}$	$\frac{3}{4}$	2	$6\frac{15}{16}$	$6\frac{1}{2}$	7	6	$86\frac{1}{2}$	76	63	50	$\frac{1}{8}$	$\frac{5}{8}$	27000
5	9	$6\frac{1}{8}$	$6\frac{1}{8}$	$\frac{3}{4}$	2	$6\frac{15}{16}$	$6\frac{1}{2}$	7	$6\frac{1}{2}$	$86\frac{1}{2}$	76	63	50	$\frac{1}{8}$	$\frac{5}{8}$	31000
$5\frac{1}{2}$	10	$6\frac{5}{8}$	$6\frac{5}{8}$	$\frac{3}{4}$	2	$7\frac{15}{16}$	$6\frac{1}{2}$	8	7	$88\frac{1}{4}$	77	63	50	$\frac{1}{8}$	$\frac{5}{8}$	38000

MANUFACTURE

Process. Unless otherwise specified, the steel shall be made by the open-hearth process.

Discard. A sufficient discard shall be made from each ingot to secure freedom from injurious piping and undue segregation.

Turning. The forgings shall conform to sizes and shapes specified by the purchaser.

Unless otherwise specified by the purchaser, axles, shafts, and similar round forgings shall have a collar approximately 2 inches in width left rough forged on each forging, and the remainder of the forging shall be rough turned with an allowance of $\frac{1}{8}$-inch on the surface for finishing.

CHEMICAL PROPERTIES AND TESTS

Chemical Composition. The steel shall conform to the following limits in chemical composition:

Carbon	not over 0.60 per cent
Manganese	0.40 to 0.70 per cent
Phosphorus	not over 0.05 per cent
Sulphur	not over 0.05 per cent

Ladle Analyses. An analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt, a copy of which shall be given to the purchaser or his representative. This analysis shall conform to the requirements specified under Chemical Composition.

Check Analysis. Analyses may be made by the purchaser from a forging representing each melt, which shall conform to the requirements specified under Chemical Composition. Drillings for analysis may be taken from the forging or from a full-sized prolongation of the same at any point midway between the center and the surface; or turnings from a tensile-test specimen may be used.

In addition to the complete analysis, a phosphorus determination may be made by the purchaser from turnings from each tensile-test specimen, and this determination shall conform to the requirements for phosphorus specified under Chemical Composition.

PHYSICAL PROPERTIES AND TESTS

Tensile Tests. After annealing, the forgings shall conform to the following minimum tensile properties:

Tensile strength (lb. per sq. in.)	80000
Elastic limit (lb. per sq. in.)	50 per cent of tensile strength
Elongation in 2 inches	22 per cent
Reduction in area	35 per cent

The elastic limit shall be determined by means of an extensometer.

Bend Tests. The bend-test specimen shall bend cold through 180 degrees around a 1-inch flat mandrel having a rounded edge of ½-inch radius, without cracking on the outside of the bent portion.

Location of Test Specimens. Tension- and bend-test specimens shall be taken from a full-sized prolongation of any forging. The axis of the specimens shall be located at any point midway between the center and the surface of the forging and shall be parallel to the longitudinal axis of the forging.

The bend-test specimen shall be ½-inch square in section, with corners rounded to a radius of not over $\frac{1}{16}$-inch, and need not exceed 6 inches in length.

MARKING

Marking. Each billet shall be legibly stamped with an identification number representing melt, which shall be transferred to the final forging immediately after reduction of billet has been completed.

Before annealing, each forging shall be stamped with a shop identification number. These shop numbers are to permit of identifying the forgings in each annealing charge to determine the number of physical tests as required.

The name or trade mark of the manufacturer, identification number, and inspector's mark shall be legibly stamped on each finished forging in location indicated by the purchaser.

The manufacturer shall report to the purchaser upon each shipment the number of annealing charges, together with the melt numbers and identification numbers of forgings included in each annealing charge.

INSPECTION AND REJECTION

Inspection. The entire process of manufacture of forgings shall be subject to purchaser's inspection, unless otherwise specified

The inspector representing the purchaser shall have free entry at all times while purchaser's order or contract is being executed to all parts of the manufacturer's works which concern the manufacture of forgings ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy the latter that forgings are being furnished in accordance with these specifications. Tests and inspection shall be made prior to shipment.

The purchaser may make tests to govern the acceptance or rejection in his own laboratory or elsewhere. Such tests, however, shall be made at the expense of the purchaser.

Journal Boxes and Bearings. The Railway Association has recommended the general dimensions for journal boxes to correspond with the journal dimensions of Table I. One of these boxes is shown in detail in Fig. 17, and its relation to the adjacent parts

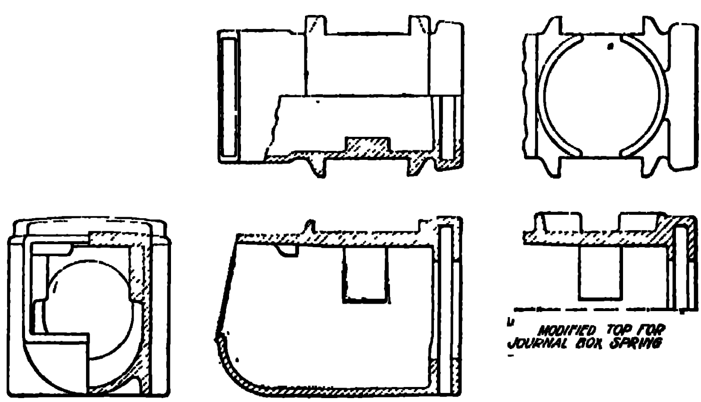


Fig. 17. American Electric Railway Engineering Association Standard Journal Boxes

of the truck can be seen in Fig. 14. It is a malleable-iron casting with guide grooves on the sides, into which fit the truck pedestal. On top of the box is the seat for the equalizer bars, the ends of which rest thereon.

The two ends of the box have openings: one to admit the axle; and the other, which is covered by a spring lid, to permit cleaning the inside of the box and replacing the grease and waste (or the oil) used in lubrication. Inside the box are the lugs which keep the journal bearing in position. In Fig. 18 are represented such a journal bearing and the wedge placed above it to hold it in place. The space inside the journal box is sufficient to accommodate the journal, the bearing, and either a quantity of grease-

soaked cotton waste or a quantity of oil with a simple ring or wick device to feed it to the journal. As the journal bearing surrounds only the upper part of the journal, the lower part is in

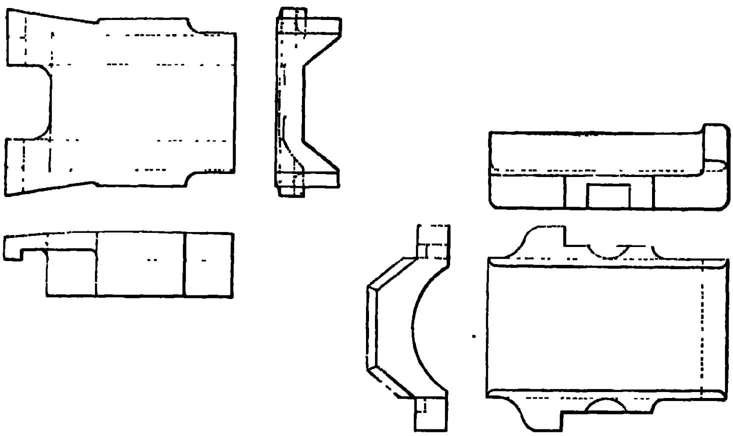


Fig. 18. M.C.B. Journal Bearing and Wedge

contact with the lubricant. On the wheel, or inner, end of the box is a thin chamber open at the bottom, which permits excess lubricant to flow out upon the track rather than upon the wheels.

In Fig. 19 are shown the journal box, bearing, and wedge in their proper relation.

Brake Shoes. Cars are brought to rest through friction between the rims of the wheels and cast-iron blocks pressed firmly against them. These blocks, or *shoes*, are curved to fit the rims

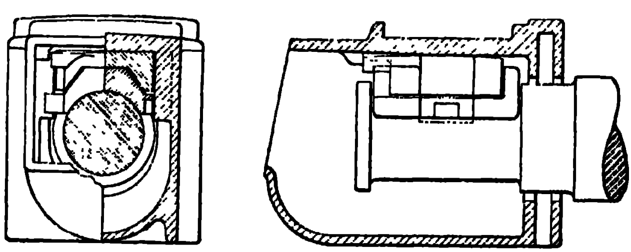


Fig. 19. Journal Box with Journal and Bearing in Position

of the wheels so as to give the best possible grip. The brake shoes wear away very rapidly in service, so that they must be hung in such a manner as to permit them to be replaced readily.

They are, therefore, carried in supports called brake heads, to which they are attached by single keys. The heads, in turn, are hung by means of some kind of a link or other support from a fixed point on the truck, *BH*, Fig. 11. In Fig. 20 is given a picture of a combined shoe and head. Fig. 21 is from the A.E.R.A. Standardization Report. It is intended to give an accurate idea of the details of Fig. 20. On account of the irregular shape of the parts, they are difficult to show clearly in drawings. The principal point is to see how the brake shoe is supported in the head. The shoe is shown in the head in elevation and section at the bottom of the illustration; and at the top is given a plan without the head. The shoe consists essentially of a curved iron block, somewhat over $1\frac{1}{2}$ inches thick and flanged to fit the rim of a car wheel. The shoe bears upon both the tread and the flange of the wheel. Projecting from the upper side of

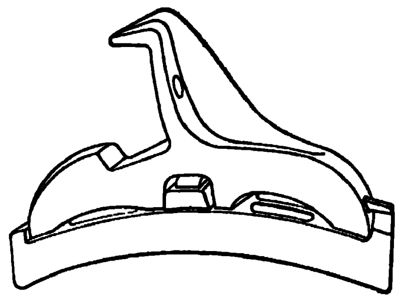


Fig 20 Brake Shoe and Head

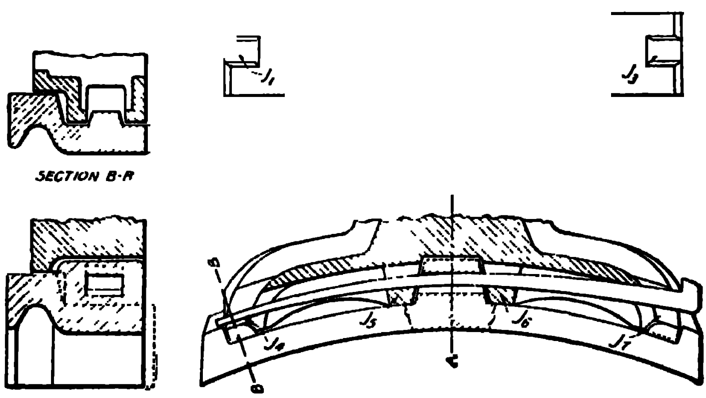
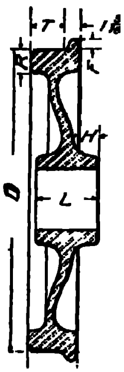


Fig 21 American Electric Railway Engineering Association Standard Brake Shoe

the shoe are lugs J_1, J_2, and J_3, by which it is held in proper relation to the supporting head. The center lug J_2 has a rectangular hole through it.

TABLE II

Specifications for Standard Steel Wheel



RELATION OF TREAD WIDTH TOTAL WIDTH AND FLANGE HEIGHT

T	W	F
$2\frac{1}{2}''$	$3\frac{11}{16}$	$\frac{3}{4}''$
$3''$	$4\frac{3}{16}$	$\frac{7}{8}''$
$3\frac{1}{2}''$	$4\frac{11}{16}$	$\frac{7}{8}''$

ROLLED STEEL WHEELS PROPOSED STANDARD SIZES

D	T	R	H	L
33"	$2\frac{1}{2}''$ or $3''$	$2\frac{1}{2}''$	$1\frac{15}{16}''$ $2\frac{15}{16}''$	$5\frac{1}{2}''$
34"	$2\frac{1}{2}''$-$3''$-$3\frac{1}{2}''$	$3''$	$1\frac{15}{16}$ $2\frac{15}{16}''$	6"
35"	$3''$-$3\frac{1}{2}$	3	$1\frac{15}{16}'$ $2\frac{15}{16}''$	6'
36"	$3''$-$3\frac{1}{2}''$	$2\frac{1}{2}''$	$1\frac{15}{16}''$ $2\frac{15}{16}''$	6"
37"	$3''$-$3\frac{1}{2}'$	3"	$1\frac{15}{16}$ $2\frac{15}{16}''$	6"

The head is a casting with projecting lugs J_4, J_5, J_6, and J_7. The center lugs J_5 and J_6 have rectangular holes corresponding to that in lug J_2 of the shoe. These holes accommodate a taper key which holds the shoe and head together. The end lugs of the head J_4 and J_7 fit loosely over the corresponding lugs J_1 and J_3 on the shoe. Sufficient space is allowed over shoe lugs J_1 and J_3 to permit the taper key to pass through loosely.

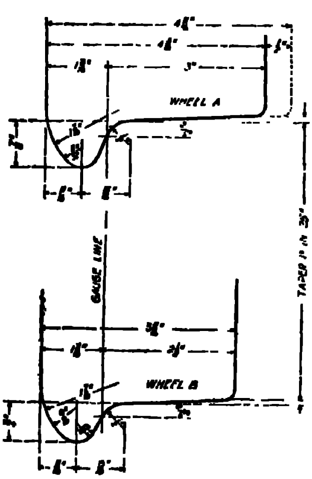


Fig. 22. American Electric Railway Engineering Association Standard Wheel Flanges

Wheel Treads and Flanges. The standards of the Association are shown in Fig. 22 for wide- and narrow-tread wheels. The peculiar form of the contour has been determined from the experience of many roads as that best adapted for keeping the wheels on the rails and giving good wearing qualities. Uniformity in this matter is especially desirable so that the wheel manufacturers can supply wheels from stock without keeping too many varieties on hand. The cost of patterns and tools is reduced, and the wheels can be made more cheaply. By the use of standard wheels, equipment can be interchanged between roads.

Car Wheels. *Parts.* A wheel is shown in cross-section in the cut given in connection with Table II. It consists of the hub, the rim, and the web, or spokes. A projection of the rim, which is necessary to hold the wheel on the rails, is the flange. The hole in the center is the bore, and the outside slightly conical surface of the rim is the tread. The rim may be of one piece with the body of the wheel, or it may carry a steel tire.

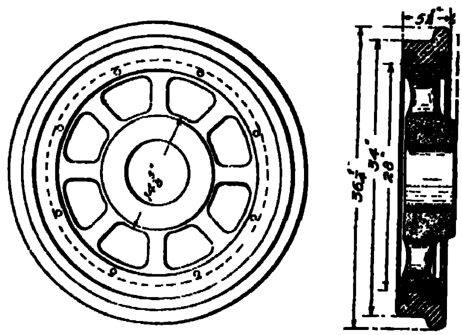


Fig 23 Wheel

Cast-Iron Wheel. The cheapest wheel is one made of cast iron with a hardened tread. Two different styles of cast-iron wheels are shown as parts of the trucks in Figs. 9 and 14. These illustrations should be examined with a view to determining the forms used to economize material and to give strength and stiffness. The tread is hardened, or chilled, by casting the metal against an iron band placed in the sand mold to form the tread. The result is such a hard tread surface that only an emery grinder will cut it. The principal objections to chilled wheels are the difficulty of truing them and the danger due to chipped flanges and brittle wheels. Cast iron itself is liable to flaws, and this liability is increased by the chilling. For low-speed service, however, chilled wheels are entirely satisfactory.

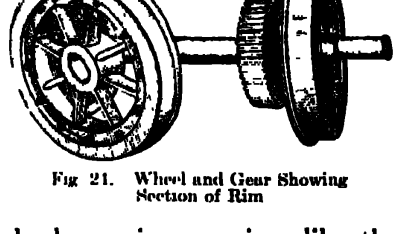


Fig. 21. Wheel and Gear Showing Section of Rim

Rolled-Steel Wheel. The rolled-steel wheel and the steel-tired wheel are preferred for high-speed service. Such wheels are free from the objections to chilled wheels, and this is well worth the greater cost. As the rolled-steel wheels are in one piece like the cast-iron wheels, they are inherently preferable to the steel-tired wheels, which are built up of several pieces. The cross-section of a steel wheel recommended by the A.E.R.A. Committee on Equipment is given in connection with Table II. By one process

the rolled wheels are made from steel ingots, sliced cold into billets, each of which contains steel for one wheel. The billet is then pressed hot under enormous pressure in a hydraulic press into

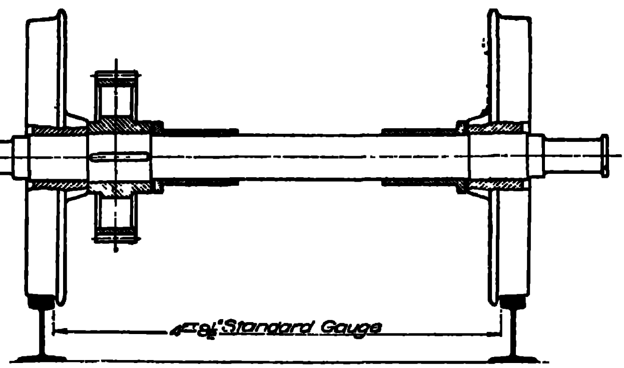


Fig. 25. Part Section of Wheels, Axle, and Gear

somewhat the form of the wheel; next, a hole is punched through the center; and finally, the wheel is rolled in a very heavy mill to the desired form. In this mill the rim is surrounded by rolls

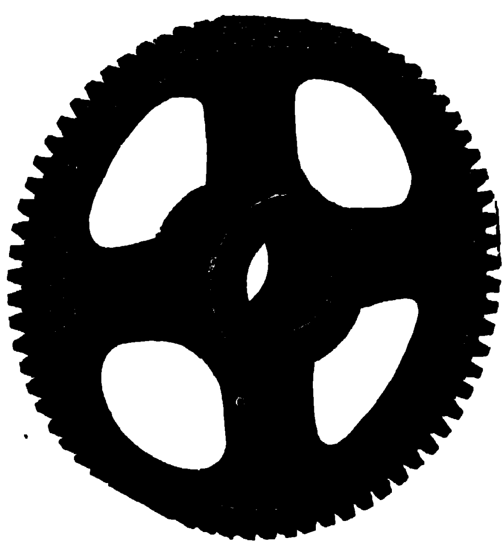


Fig. 26. Solid Cast Gear for City Service

except in the portion covered by the web. While it may seem strange to make a wheel without cutting, it is possible, because steel "flows" just like lead if the pressures applied are great

enough. The rolling process, also, is beneficial to the metal in rendering it compact and homogeneous.

Steel-Tired Wheel. While solid-steel wheels are coming into use, the built-up wheel is more usual at present. This consists of cast or forged hub, spokes, and rim, with a steel tire shrunk on Such a wheel is shown in elevation and in section in Fig. 23. The drawings show the light retaining rings riveted to the rim on the two sides of the tire to prevent the latter from slipping off, which it tends to do when it wears thin. As stated, the tire is shrunk on. When cold, its internal diameter is slightly less than that of the external diameter of the rim. When heated, it expands sufficiently to allow it to slip over the rim; and when it cools, it contracts and binds the rim firmly. The tire is about 3 inches thick when new, and it can be worn down until it is less than 1 inch thick. Another satisfactory arrangement of tire is that illustrated in Fig. 24. There are no retaining rings required in this case, the tire being bolted to the rim. Such a tire cannot get loose.

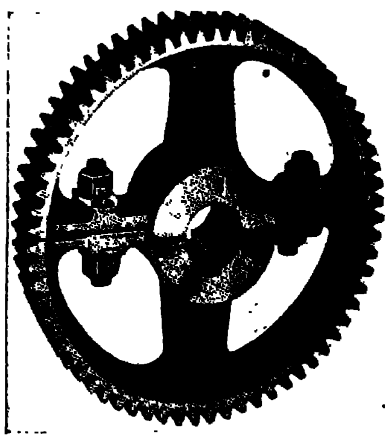


Fig. 27. Split Cast-Steel Gear for City Service

Axle Gears. On the car axle, Fig. 25, is mounted a gear wheel which meshes with the pinion, or small driving gear, on the motor shaft. The axle gear is of cast steel and of the form shown in Figs. 26 and 27. Fig. 26 illustrates a solid gear which must be put on before the second wheel is pressed into position. The position of the axle gear on the axle can be seen in the cut accompanying Table I and in Fig. 25. The gear is keyed to the axle to prevent turning. In Fig. 27 is shown a gear which is split along a diameter with the two halves bolted together. This gear can be mounted on an axle without disturbing a wheel. A recent form of gear, Fig. 28, is provided with a removable rim, so that the same center can be used even after the teeth wear out.

The gear rim is cut accurately with involute teeth, great care being taken to insure good wearing surfaces to prevent friction. There is always, however, a considerable loss at this point, 3 per cent or more of the power of the motors being absorbed.

Except for axles of the old type on which the wheel and gear fit are the same diameter, solid gears have practically replaced the

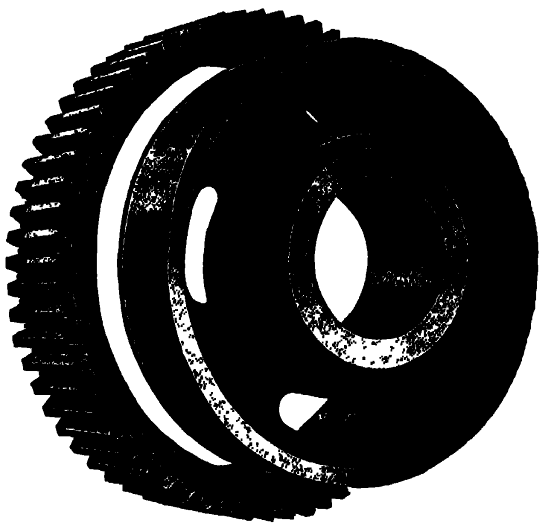


Fig. 28. Composite Gear with Untreated Center o Cast-Steel

split type, owing to their superior operation, freedom from broken bolts, loose gears, scored axles, and lower first cost.

MOTORS

DIRECT-CURRENT SERIES TYPE

Construction. The motor used for traction work is of the *series type* (usually with commutating poles also), the armature and both field circuits being connected in series. A simple diagram of these circuits is shown in Fig. 29.

The essential parts of this motor are: (1) a steel magnet frame which carries pole pieces for the main and commutating poles and also forms the enclosing case for protecting the motor; (2) an armature of the series or wave-wound type with commutator; and (3) a brush-holding mechanism supporting two sets of

carbon brushes mounted at right angles, with suitable cable leads for carrying the current. In Figs. 30 and 31 is shown a railway motor of the box type viewed from the axle side and the susp'n-

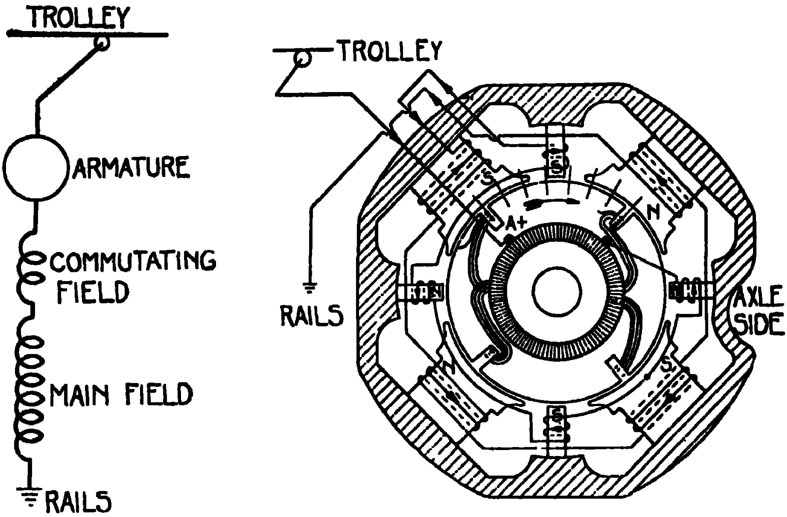


Fig 29. Diagram of Field and Armature Circuits in Traction Motor

sion side, respectively, while Fig. 32 shows a similar motor having a split frame with the lower frame down for inspection.

The motor consists of a cast-steel frame approximately octagonal in form cast in one piece and provided with bored openings at each end. The armature, pole pieces, and field coils can be inserted or removed through one of these openings. The main pole cores are built up of laminated steel and securely bolted to the magnet frame. The commutating poles are of drop-forged steel bolted to the frame between the main poles. The armature is supported by bronze bearings, which are lined with babbit and supported in the frame heads of the motor. These frame heads are securely bolted to the end of the magnet frame.

Fig. 30. 40-Hp. Railway Motor, Axle Side

The motor is supported on one side by axle bearings, which are carried directly on the car axles. On the opposite side are suspension lugs, by means of which the remainder of the weight of the motor is supported by a suspension bar forming a part of the truck frame. Suitable openings are provided over the commutator to allow easy access to the commutator and brush holders. Other handholes are also provided for convenient inspection of the interior of the motor. The holes through which the armature and field cables are brought out through the case are lined with insulating bushings to prevent the possibility of grounding on the frame.

Fig 31. Railway Motor, Suspension Side, Split-Frame

Ventilated Motors. Until a few years ago railway motors were constructed totally enclosed, and all dissipation of heat was effected through the steel enclosing case. During the past few years, however, the ventilated motor has been developed and is now standard for railway work. In these motors there is a definite circulation of air obtained by means of a fan which is an integral part of the armature-core head. Air is taken from the outside of the motor through suitable openings, passed through longitudinal ducts in the armature core, Fig. 33, and around the field coils, and exhausted to the outside air. This construction differs from the earlier types, which were cooled by means of a circulation of air within the motor, the heat being passed from the air to the motor frame and thence radiated from the steel case. In these motors the ventilating ducts in the armature core are radial, that is, the

Fig. 32. Railway Motor with Lower Frame Down for Inspection

air passes from the armature spider radially to the surface of the armature.

Types of Ventilation. In general, there are two methods of motor ventilation. The first is known as the series type, Fig. 34, in which the air is taken in at one end of the motor through a screened opening, passed around the fields, and then longitudinally through the armature core, reaching the outside air through other ventilating openings. The second type is known as multiple ventilation, Fig. 35, in which the air is taken in at one end of the motor by a double fan, which passes two currents of air through the motor, one through the armature core and the other over and

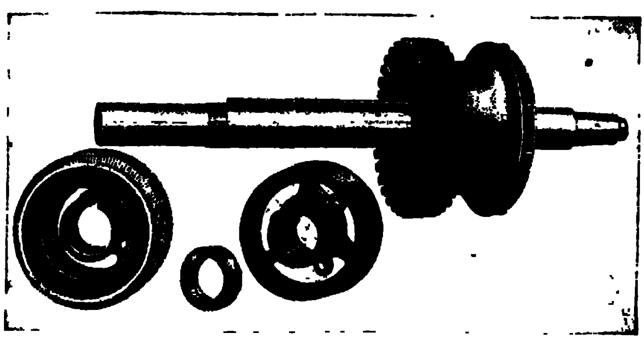


Fig. 33. Armature Core Partially Assembled on Shaft

around the field coils. The heated air is then exhausted at the opposite end of the motor.

Enclosed vs. Ventilated Motor. With the ventilated type of construction it may easily be seen that the amount of ventilating air is increased when the motor speed is increased. The capacity of the motor is much greater when operating in high-speed interurban service than when employed in low-speed city service. It is estimated, however, that for a city service having frequent stops and a schedule speed of 10 miles per hour, the ventilated motor using the series type of fan is capable of handling from 10 to 15 per cent heavier loads than the totally enclosed motor of the same hp. rating. For interurban service, operating at a schedule speed of 18 miles per hour or more, the series-ventilated motor will handle from 25 to 30 per cent greater loads than an

enclosed motor of the same hp. rating. Because of the method of rating railway motors, the hourly rating of the ventilated motor is not very much greater than that of the enclosed motor. This is

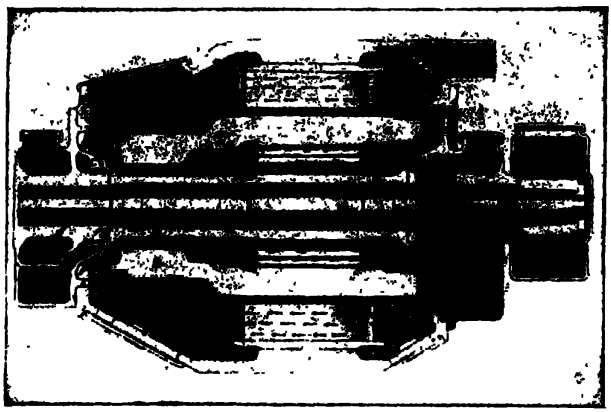


Fig 34. Series Method of Motor Ventilation

partly due to the definition of hp. rating as prescribed by the American Institute of Electrical Engineers.

Nominal Rating. The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in

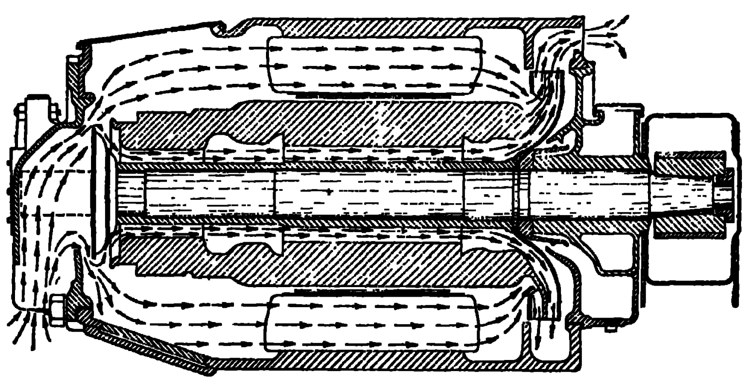


Fig. 35. Multiple Ventilation of Railway Motor

kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90° C. at the commutator and 75° C. at any other normally accessible part after one hour's continuous

run at its rated voltage (and frequency in the case of an a.c. motor) on a stand with the motor covers arranged to secure maximum ventila-

Fig. 36. Main and Commutating Field Coils

tion without external blower. The rise in temperature as measured by resistance shall not exceed 100° C.

Under this rule it should be noted that the totally enclosed motor is tested with all covers removed, allowing much greater ventilation than is the case under actual service.

Box and Split-Frame Motors. By far the larger part of all the railway motors now being manufactured in this country are of the box type, although there are many split-frame motors in service. The object of the split-frame motor, Fig. 32, is to facilitate inspection from a pit without removing the motor from the truck frame. Many of the smaller roads in the early days had no facility for lifting a car body from the trucks and on this account objected to the box type of motor; however, methods have now been devised by most railway systems for handling the box-frame type. The principal advantages of the box frame over the split frame are as follows: (1) larger output for same space and weight; (2) unbroken magnetic circuit of the frame and greater protection

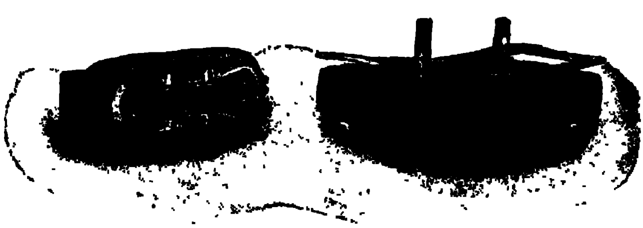


Fig. 37. Main Pole and Commutating Field Complete

to field-coil connections; and (3) elimination of the joint in the frame, giving freedom from oil and more room for field coils and axle bearings.

Field Poles and Coils. The field coils, Fig. 36, which carry the current around the pole pieces, Fig. 37, and thus form the magnetic field of the motor, are all wound of strap copper insulated

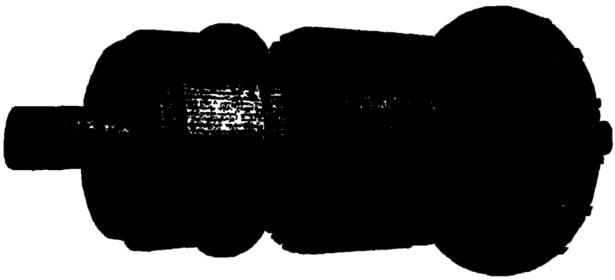


Fig. 38. Commutator, Core, and Shaft

between the turns with asbestos insulation. After being entirely wound up, the coil is dipped in insulating material and baked to prevent possibility of injury by rough handling or from the penetration of moisture. These coils are held in position on the pole pieces by the projecting pole tips with suitable protection by means of pressed-steel spring seats which distribute the pressure on the coil and at the same time hold it away from the frame. These flat wheel springs prevent vibration and injury to the insulation.

Armature Core and Coils. The armature core of the ventilated motor is built up of thin steel sheets insulated from each other by coats of japan and clamped firmly together between steel end plates. Each of these sheets has a number of holes

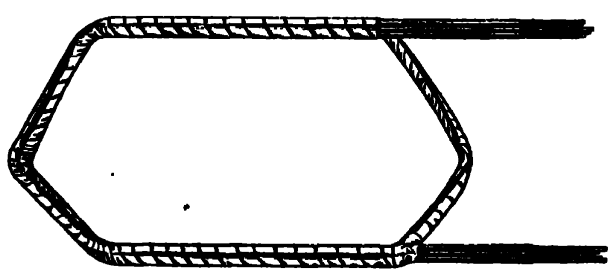


Fig 39 Armature Coil

through the central portion, and when completely assembled, these form longitudinal ducts for the passage of cooling air. This core is pressed on to the armature shaft and keyed in position

before assembling the coils in the slots. Fig. 33 shows an armature core partially assembled on the shaft, while Fig. 38 shows the commutator and the core mounted on the shaft.

In the slots of the armature, Fig. 38, are placed coils similar to those shown in Fig. 39. Here are three coils, wound side by side and insulated together, each coil having two or three turns. The insulation consists of the cotton covering on the individual wires, of fuller board partitions between coils, and of a wrapping of rope paper and linen tape. The whole is impregnated with insulating varnish. A set of three assembled and insulated coils fills one-half a slot. In winding the armature with these coils forty-one are required, this being the number of slots. One side of each coil is laid in the bottom of a slot, and the other side of each coil is placed in the top of the slot, into which it naturally fits. Bands made of bronze wire are wound about the core to hold the coils in place. In connecting the coils to the commutator the simplified diagram of Fig. 40 will be found useful. This has, for simplicity, but eleven slots, with one coil in each, and eleven commutator bars, whereas the motor under discussion has one hundred and twenty-three coils and bars. However, the principle is exactly the same. In the actual motor the three coils in one slot are treated as if they occupied separate slots in the diagram.

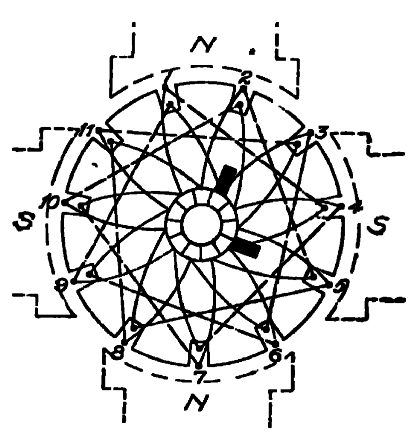


Fig 40. Diagram of Armature Winding

In Fig. 40 the path of the winding can be followed thus: A coil is in the top of slot *1* and in the bottom of slot *4;* another in the top of *2* and the bottom of *5*, etc. One terminal of the first coil goes to commutator bar *10*, the other to *4;* the terminals of the second coil to *11* and *5;* and thus around the core until the connections are complete.

This is a wave winding, and when connected in this way and with the brushes placed as shown, there are two parallel paths

through the winding from brush to brush. Each path is through the field under all four poles, so that any possible inequality of the fields does not affect the counter-e.m.f. or the distribution of the current in the armature.

Commutator. The commutator is shown in section in Fig. 41. It does not differ essentially from the usual form and consists of 123 hard-drawn copper bars, separated by soft mica and assembled in cylindrical form. These bars are held together in the manner

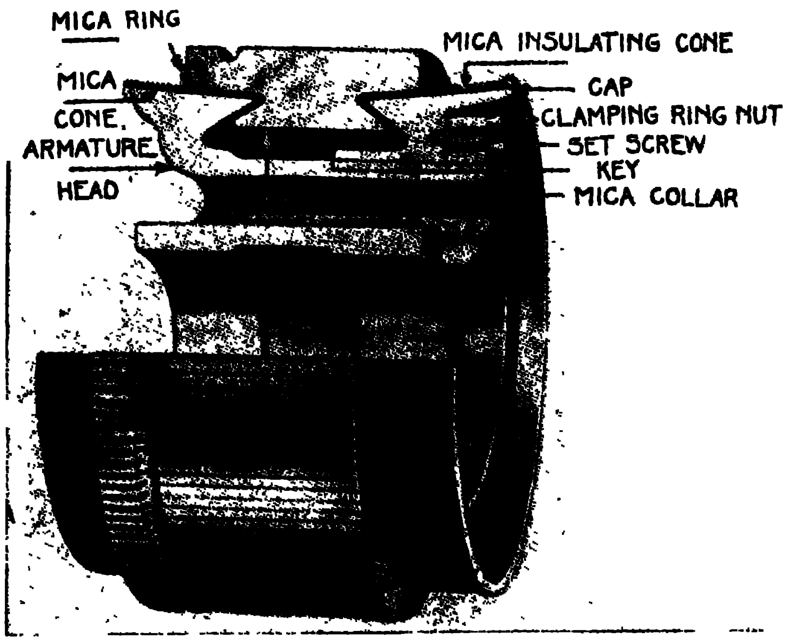


Fig. 41. Commutator Section Showing Construction

usually followed with this kind of construction. A cast-iron shell has a V-shaped flange at one end. The ends of the bars are formed to fit under this flange; the other ends fit under a steel taper ring, which is pressed against the bars by a clamping nut. The bars are insulated from the bushing and ring by molded mica. One end of each bar is slotted for the accommodation of the leads from the armature winding.

The complete armature, with windings and commutator in place, is shown in Fig. 42.

Brushes and Brush Holders. The brushes for railway motors are carbon blocks, 2 inches, more or less, in width, $\frac{1}{2}$ to $\frac{3}{4}$ inch in thickness, and 2 inches, more or less, in length. The exact size differs with the style of motor. These brushes are mounted radi-

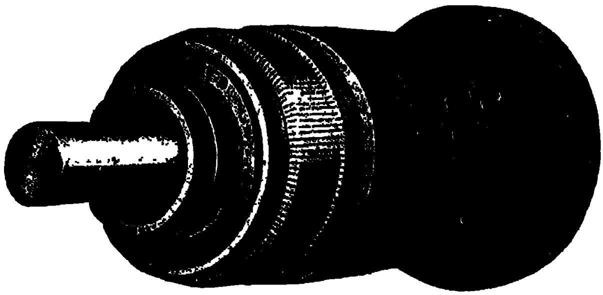


Fig. 42. Complete Armature with Fan

ally, or nearly so, and they are pressed against the commutator by spring pressure fingers. The brush holder of this motor is shown more in detail in Fig. 43. It comprises a brass frame in which two brushes, placed side by side, slide easily. They are pressed radially inward by pressure fingers which are pulled against the ends of the brushes by adjustable-tension springs. The pressure fingers may be raised for replacing the brushes by means of the bent levers shown.

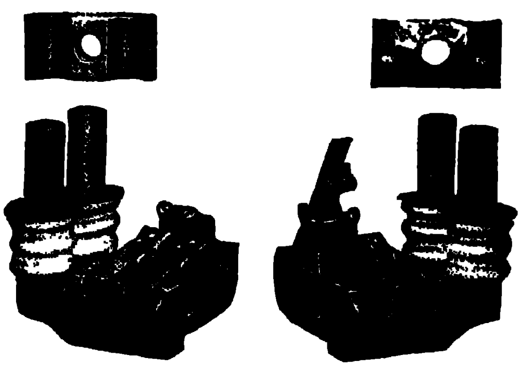


Fig. 43. Brush Holders

The brush-holder casting is fastened by means of insulated studs to the inside of the motor frame and insulated therefrom by means of a porcelain insulator. The lugs by which it is clamped to the frame permit radial adjustment of the holder.

The armature terminal lugs are cast as part of the brush holder so that the current may be conducted away from a point as near the commutator as possible. With this arrangement no unnecessary heat is produced.

Bearings. The set of four bearings is shown in Fig. 32. All the bushings are cast-iron cylinders lined with babbitt metal; these are supported in cast-iron housings. The armature-bearing housings have bored seats and are clamped between the two halves of the field casting. The axle-bearing bushings are split;

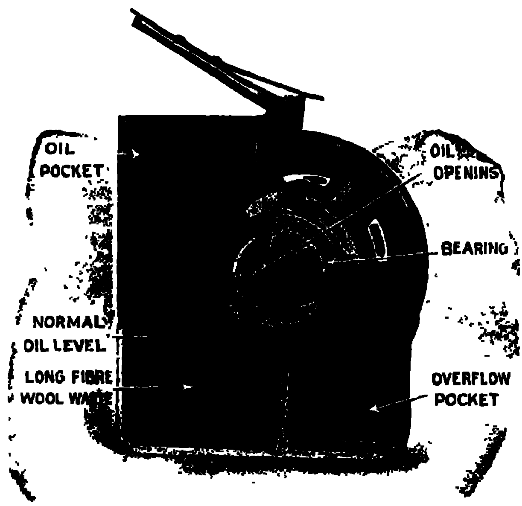


Fig. 44 Cross-Section of Bearing Housing

they are supported by hollow extensions from the main frame and firmly clamped between these and cast-steel axle caps above.

The bearing housings not only provide support for the bushings, but also form chambers for the lubricant. The section of one of the bearings of this motor is shown in Fig. 44. A large chamber at one side of the bushing is packed with wool waste. This becomes saturated with oil, which is poured into the smaller chamber to the left of it in the illustration. The side of the bushing is cut away to allow the oil-soaked waste to come into contact with the shaft, which is thus well lubricated. Surplus oil passes into the chamber to the right and spills into the roadway.

An important feature of the lubrication is the oil ring which is carried on each end of the motor shaft to prevent oil from getting into the armature winding and the commutator. Such a ring is shown to the left of the commutator in Fig. 42. The ring revolves in a groove in the bearing housing. As the oil reaches this ring it is thrown outward by centrifugal action and is discharged outside the frame.

Leads and Connectors. Four flexible cables are brought through the motor case, two each from armature and field. The cables are rubber covered and protected by an extra braided covering and pass through holes bushed with semi-soft rubber. As the cables must be disconnected frequently in everyday use, their terminals are provided with connectors by which they may readily be coupled to the motor wiring. A pair of these connectors is shown in Fig. 45.

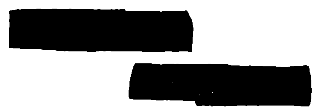


Fig. 45 Field Lead Connections

Suspension. The method of suspending this motor may easily be understood from an examination of the suspension lugs shown in Fig. 31 and of the suspension bars which form parts of the trucks. The crossbars are bolted to the suspension lugs, the cushioning effect which is necessary being provided by spring support of the crossbars.

Gearing. As the speed of the motor shaft is much greater than that desired at the car axle, a considerable reduction, by means of the spur-gear wheels, is necessary. On the motor axle is the forged-steel pinion; this is keyed to the shaft and is held on a taper fit by means of a nut. The end of the shaft is threaded. The taper fit makes a rigid mounting for the pinion which is easily removed. On the car axle, as already explained, is the cast-steel axle gear, usually split for ease of removal. The pinion has accurately cut teeth to correspond with those of the axle gear.

Gear Case. To protect the gears from dirt, they are surrounded by a malleable-iron box, mounted securely on the motor frame. Lugs are provided on the frame for the purpose. The gear case is made in two parts, as otherwise it would be impossible to put it in position. While the motor which is being studied has a cast case, it should be noted that cases made of sheet iron are coming into favor because there is considerable breakage of

the cast cases. The malleable-iron cases are, however, standard practice at present.

Operating Characteristics. As the name implies, the armature and field circuits of the series motor are connected in series, consequently the same current flows in both. As a result of this connection the speed, torque, and current relations are different from those in other types of motor. The relations of these quantities are shown in Fig. 46. In these curves the current values are

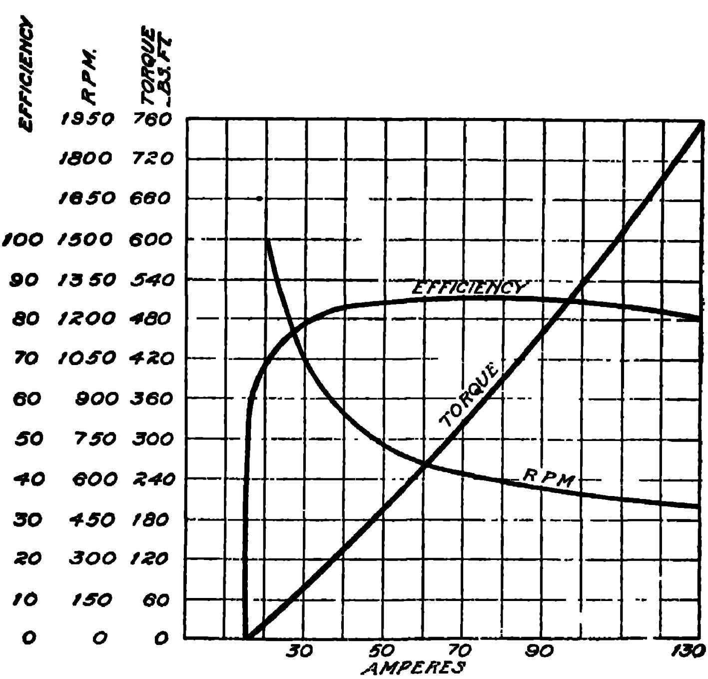


Fig. 46. Series-Motor Characteristic Curves

given as abscissæ, and the torque, r.p.m., and efficiency values as ordinates.

Take, for example, the curve between torque and current. The curve shows that the torque increases with the current, being nearly proportional to it. This torque is proportional to the strength of the field and to the current with a given number of armature inductors. If there were no saturation in the magnetic field, the torque would, therefore, be proportional to the square of the current; but there is a great deal of saturation, especially in the

armature teeth, hence the torque curve does not bend upward very much.

The speed of a given motor armature is proportional to the strength of the field and to the applied e.m.f., neglecting the e.m.f. drop in the armature and field resistance. It is necessary for the armature, by the cutting of the inductors across the field, to produce a counter-e.m.f. equal to the impressed e.m.f. (neglecting, as stated, the resistance drop). Therefore, in a weak field the armature runs faster, and in a strong field, slower. This is clearly brought out in the curves, where it will be noted that a small value of current—or weak field, as the same current flows in the field circuit as in the armature circuit—corresponds to high speed, and vice versa.

Example. A 20-ton car is equipped with two motors to which the curves of Fig. 46 apply. The motors are so geared to the car axles that the

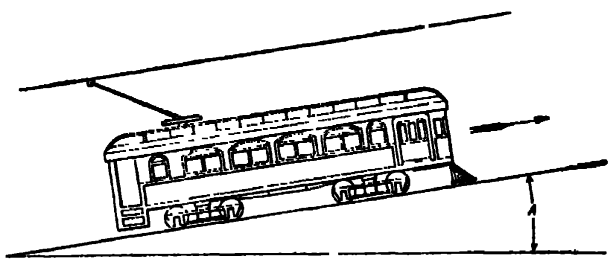


Fig 47 Diagram of Car on Grade

latter run slower by the ratio 1:4.06. The car wheel is 33 inches in diameter. Assume that it requires 20 pounds per ton, applied along the direction of motion, to overcome friction. Determine with the aid of the curves the following items: (a) At what speed will the car mount a 5-per cent grade? (b) How much current will it draw from the line while climbing this grade? (c) How much mechanical power will each motor develop? (d) How much electrical power will each motor take? (The voltage for which the speed curve was derived is 500.) (e) What is the efficiency of the motors?

(a) and (b) In Fig. 47 is represented the car on the grade. To pull it up the grade will require a force made up of two components: (1) that required to overcome friction; and (2) that required to lift the car. The former is 20 pounds per ton, or 400 pounds. The latter is 5 per cent* of the weight of the car, or 2000 pounds. The total force required is 2400 pounds, which is independent of the speed, the friction being assumed constant. This force is produced by two motors, hence each must produce one-

* For convenience it is customary to define the per cent grade of a track as the ratio of the lift to the distance traveled, or the sine of the angle A, multiplied by 100. The per cent of grade is the ratio of rise to horizontal distance traveled.

half. To use the curves requires the transfer of this force to terms of torque. Each motor must deliver at the wheel tread a tractive effort of 1200 pounds. Therefore

$$\text{Axle torque} = \frac{16.5}{12} \times 1200 = 1650 \text{ lb. ft.}$$

or pounds at 1 foot radius. The motor torque is less than this—as the motor shaft runs faster than the car axle by the ratio of the number of gear teeth to pinion teeth—by the gear ratio. Or

$$\text{Motor torque} = 1650 \times \frac{1}{4.06} = 406.5 \text{ lb. ft.}$$

From the curves this torque is seen to correspond to 80 amperes per motor, or 160 amperes for the car, and this number of amperes corresponds to 588 r.p.m.

To find the miles per hour from the r p m., note that one motor-shaft revolution corresponds to $\frac{1}{4.06}$ revolution of the car axle. As the wheel is 33 inches, or $\frac{33}{12}$ feet, in diameter, one revolution of the wheel advances the car $\frac{33}{12} \times 3.1416$, or 8.65 feet (3.1416 is the ratio of the circumference of a circle to its diameter). One revolution of the motor armature then advances the car $\frac{8.65}{4.06}$, or 2.13 feet. As the motor armature makes 588 r.p.m. in this case, the corresponding rate of car travel is

$$\text{Speed} = 2.13 \times 588 = 1252 \text{ feet per minute}$$

then

$$\text{Miles per hour} = 1252 \times \frac{60}{5280} = 14.2$$

Ans. 160 amperes
14.2 miles per hour

(c) The mechanical power produced by each motor is the product of the speed of a point on the torque circle—that is, of a circle of 1 foot radius —and the torque. Remembering that 1 mechanical horsepower (m.hp.) is 33,000 foot pounds per minute

$$\text{m.hp.} = \frac{588 \times 2 \times 3.1416 \times 406.5}{33000} = 45.5$$

Ans. 45.5 m.hp.

(d) The electrical power input in watts is the product of volts and amperes, or

$$\text{Watts} = 500 \times 80 = 40000$$

As 746 watts equal 1 electrical horsepower (e.hp.) the input in this unit is

$$\text{e.hp.} = \frac{40000}{746} = 53.7$$

Ans. 53.7 e.hp.

TABLE III

Motor Efficiencies for Different Track Grades

Grade	Tractive Effort per Motor	Torque	Current	Speed R P M	Speed M.P H	Efficiency
1 per cent	400	135.8	40.0	829	20.0	82.0 per cent
2 per cent	600	201.6	50.0	737	17.8	83.5 per cent
3 per cent	800	271.0	60.5	673	16.3	85.0 per cent
5 per cent	1200	406.5	80.0	588	14.2	85.0 per cent
10 per cent	2200	746.0	128.0	497	12 0	81.5 per cent

(e) The efficiency is the ratio of output to input, in this case of m.hp. to e.hp. This is usually referred to in per cent, so that the ratio must be multiplied by 100. Then

$$\text{Efficiency} = \frac{45.6}{53.7} \times 100 = 85 \text{ per cent}$$

Ans. 85 per cent

The student should, for practice, make corresponding calculations for other grades, say for 1 per cent, 2 per cent, 3 per cent, 10 per cent. The answers for these grades are given in Table III. The same principle can be applied to level track, that is, zero-cent grade. It is interesting to note that a car equipped with per series motors climbs steep grades slowly and hence does not require as much power from the line as would be necessary with constant-speed motors of the shunt type. As has been pointed out, this is due to the stronger field which is produced at slow speeds by the large currents.

Commercial Motor Curves. In making calculations of series-motor performance it is very convenient to have the characteristic motor curves in terms of current, horizontal or tractive effort, and car speed; this is possible for given wheel diameter and gear ratio. There must, obviously, be a different set of curves if either of these is changed. In the bulletins of the manufacturing companies there are usually given several sets of curves for each motor with the usual gear ratios and wheel diameters. From the data and illustrations already given the student should have no difficulty in plotting a set of curves for given wheel diameter and gear ratio if he has the motor torque and speed curves. He should also, given a set of commercial curves, be able to change them to curves for other wheel diameters and gear ratios.

A set of curves in the ordinary form is given in Fig. 48. Here the speed curve is plotted in miles per hour, instead of revolutions per minute, and the motor torque is transformed into

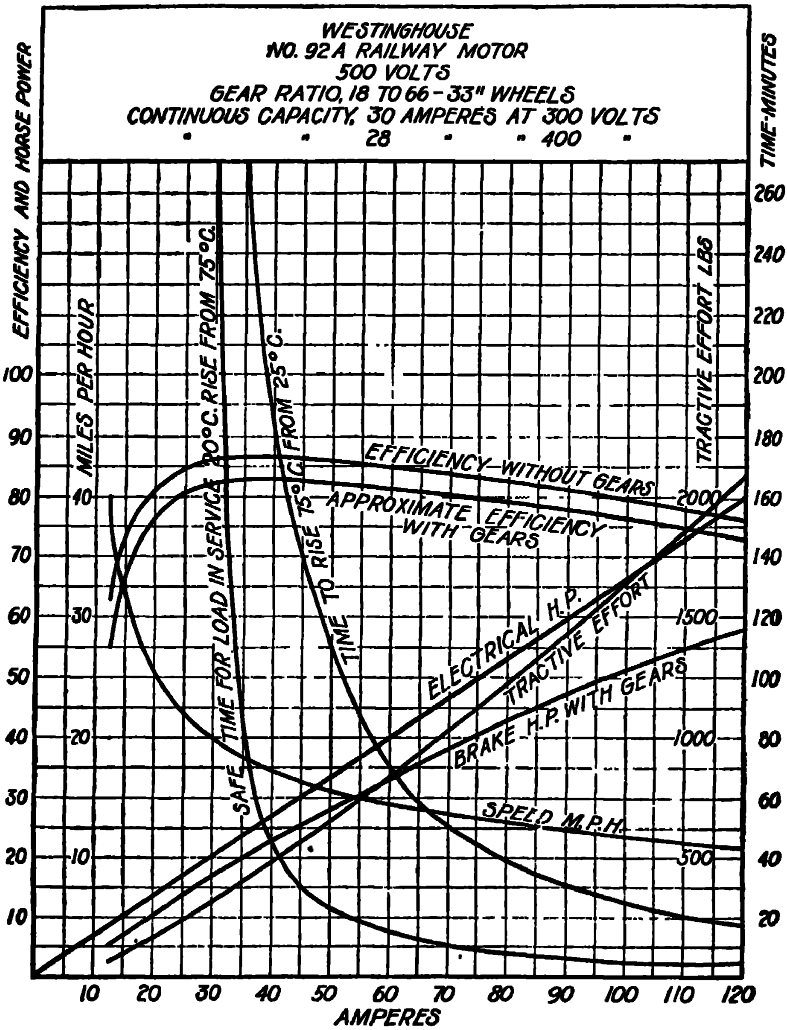


Fig. 48. Characteristic Curves of Westinghouse Railway Motor

tractive effort. This set of curves includes the effect of the gear friction, which in the previous problems was assumed to be included in the allowance for mechanical friction (20 pounds per

ton). The gears are seen to lower the efficiency about 4 per cent. As the gears are not really a part of the motor, the loss in them is not chargeable against the motor; on the other hand, as gears are almost invariably used with motors, it is necessary to know whether or not the efficiency curves as given include gear friction.

Motor Heating. The output of a railway motor, like that of other electrical apparatus, is determined by the allowable heating. A rise of temperature from 50° to 75° C. above the atmosphere is all that can be allowed. The heating is caused mainly by the power loss in the resistance of the windings and by the hysteresis loss in the armature core. Small losses also occur owing to brush and bearing friction. A curve plotted between amperes and the length of time during which this current may be safely carried is shown in Fig. 48. The heading of the curves states that the motor may operate continuously at 30 amperes and 300 volts or at 28 amperes and 400 volts. According to the curves, if the average load is such as to draw 50 amperes, the motor will heat up from 25 degrees to the limiting temperature in 110 minutes or from 75 degrees in 23 minutes. It must be allowed to cool down before it can be used again. If the current drawn be greater, the time is more than proportionately reduced, because the heating loss varies as the square of the current. A casual inspection of the curves would indicate that a railway motor would in a short time become so hot that it would have to be set aside to cool. Fortunately, however, the ordinary railway load is of a very intermittent nature, so that there is opportunity for cooling at very frequent intervals.

Another point requiring explanation is that the continuous capacity is stated at 30 amperes at 300 volts and 28 amperes at 400 volts. Why these voltages when the motor is a 500-volt motor, and why a different allowable current for each of the two voltages? It has been noted in the study of motor control that in actual operation motors are subjected to various voltages depending upon the connections and the resistance in series. The average voltage is, therefore, always less than the maximum, and may be much less when the motors are run a great deal in series. The heating of the motor depends upon the voltage as well as the current, for the reason that the voltage depends upon the speed,

other things being equal. If the voltage and speed are low, the flux in the armature core reverses less frequently and, therefore, produces little hysteresis loss, and vice versa.

On account of the intermittent nature of the load on a railway motor, it is not possible to select motors for a given equipment on the basis of heating with continuous load. Such selection can be based only on experience.

Speed Control. The principle of speed control of any constant-potential motor is that the armature inductors, by their motion through the field flux, produce an e.m.f. equal to the voltage applied to the brushes less the voltage drop in the resistance of the motor.

Example. If a motor has ½ ohm resistance, what will be its counter-e.m.f. when operating at 500 volts and drawing 50 amperes from the line?

The voltage drop in resistance is 50×0.5, or 25 volts. The counter-e.m.f. is, therefore, $500-25$, or 475 volts. The armature must rotate at such a speed as to generate 475 volts with this value of current.

Ans. 475 volts

Keeping this fundamental principle in mind, it follows that if any factor of the counter-e.m.f. be varied there will be a corresponding variation in speed. These factors are shown in the formula for the e.m.f. in a motor armature circuit

$$e=\frac{N \times \Phi \times 2p}{t \times 10^8}=E-IR$$

wherein e equals counter-e.m.f. of motor in volts; N equals number of armature inductors in series between brushes, Φ equals flux under one pole in lines of force; p equals number of pairs of poles; t equals time of one revolution in seconds, or $\frac{60}{\text{r.p.m.}}$; E equals applied e.m.f. in volts; I equals current in amperes; and R equals armature and field resistance in ohms.

The quantities in this formula which can be conveniently varied are the applied voltage E and the field flux Φ. In modern practice the method of varying the applied voltage is the only one used. The two plans formerly employed to vary the field flux with a given current in the motor were as follows: to change the number of field turns; and to shunt the field circuit with a resist-

ance circuit to deflect part of the current. Both these methods have been abandoned for the simpler plan of changing the e.m.f.

One method of varying the e.m.f. used in modern control systems is to insert resistance in the main circuit and thus cut down the voltage at the motor terminals; this plan is used only in starting as it is wasteful of power. Another method is to con-

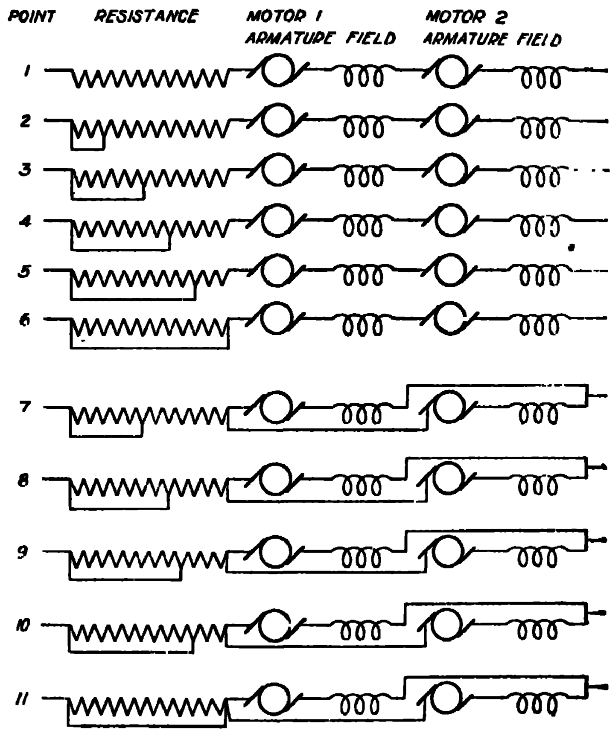


Fig. 49. Controller Diagram

nect the motors first in series and then in parallel; when the motors are in series, the line voltage is divided between them.

The connections which are made by the controller in starting and in running are given in Fig. 49. At the left are given the positions of the controller handle corresponding to the different connections; next is shown the starting resistance; then the armatures and the fields of the two motors. The connections on the different points are as follows:

(1) **Starting resistance in series with the motors, which are connected in series.**

(2) Same as (1), but with part of the starting resistance short-circuited.

(3), (4), and (5) Same as (1) and (2), but with more resistance short-circuited on each point.

(6) Motors in series. This is the slow-speed running position, each motor having one-half the line voltage.

(7) Motors in parallel with starting resistance.

(8), (9), and (10) Same as (7), but with more resistance cut out on each step.

(11) Motors in parallel. This is the full-speed running position.

The two running positions (6) and (11) are in this case the only ones in which the controller should be operated continuously as it is not only inefficient to waste power in resistance, but the resistance grids are not made with sufficient carrying capacity to stand the motor current for more time than is necessary to bring the car up to speed.

Examples. 1. The 20-ton car used in the example on page 39, while climbing the 5-per cent grade, has its motors connected in series. If the resistance of each motor is 0.3 ohm, what speed will the car now make?

The required horizontal effort, which has been assumed independent of speed, is the same as before, 2400 pounds, or 1200 pounds per motor. Each motor now gets 250 volts, and in order to produce the same torque the current in each motor must be the same as before, 80 amperes. The voltage drop in resistance in each motor is 80×0.3, or 24 volts, so that the counter-e.m.f. is $250-24$, or 226 volts. The counter-e.m.f. of each motor on full line voltage is $500-24$, or 476 volts. As all other quantities are the same as before, the speed is proportional to the counter-e.m.f. The new speed is therefore

$$\text{Miles per hour} = 14.2\times\frac{226}{476} = 6.75$$

which is slightly less than one-half the former speed.

Ans. 6.75 miles per hour

2. What will be the speed of the car if, while the motors are in parallel, a resistance of 2 ohms is connected in series with them?

The current per motor is as before, the total current being 160 amperes. This current flowing through 2 ohms produces a drop of 320 volts. The motor voltage is, therefore, $500-320$, or 180. The motor counter-e.m.f. is $180-80\times0.3$, or 156 volts. The new speed is

$$\text{Miles per hour} = 14.2\times\frac{156}{180} = 12.3$$

Ans. 12.3 miles per hour

Connections in Four-Motor Equipments. Double-truck cars ordinarily have four motors. In this case the principle of connection is the same, but the pair of motors on each truck is

treated like each of the two motors in the car just described. Fig. 50 shows the series, or half-speed, connections, and Fig. 51 the parallel, or full-speed, connections. The intermediate resistance positions are as before.

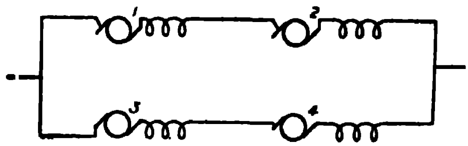


Fig 50 Motors in Series-Parallel

Reversal of Direction of Motor Rotation. Reversing the direction of the flow of current through a motor will *not* reverse the direction of rotation, because the field current and the armature current reverse at the same time. It is necessary to change the direction of the current either in the field or the armature by reversing the terminals of one or the other. The way in which this is accomplished will be explained in connection with the sections on Controllers.

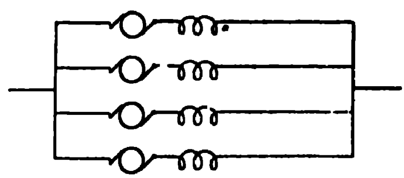


Fig. 51. Motors in Parallel

SINGLE-PHASE ALTERNATING-CURRENT MOTOR

Extent of Use. There are a number of railways in the United States employing a.c. motors, but for several reasons single-phase motors are not now recommended for city and interurban systems. One of these reasons is the development of the 1200- and 1500-volt d.c. equipment, which is eminently suited to operation at the higher voltages for interurban running and at 600 volts over city lines. One of the disadvantages of a.c. operation is found in the complications necessary to enable single-phase cars to operate in cities over the 600-volt local lines. The field of the a.c. motor car, therefore, seems to be limited to operation on electrified divisions of steam railroads, where they are not required to operate on direct current. Examples of this type of equipment are found on the Paoli division of the Pennsylvania Railroad and the New Canaan branch of the New York, New Haven and Hartford Railroad.

Comparison of D.C. and A.C. Motors. The series a.c. motor has characteristics similar to the series d.c. motor, since the direc-

tion of rotation of a series motor is independent of the direction of the current, and the d.c. motor will operate when single-phase alternating current is impressed on the commutator. Several important modifications, however, are necessary in order to adapt the series motor to a.c. service.

Necessary Modifications in Motor. *Reduction of Reactance.* The number of turns must be made as small as possible in order to reduce the reactance of the coil to the minimum amount. The effect of this is to reduce the flux under the poles if all other conditions remain the same. To reduce the effect of the weak field magnetomotive force (m.m.f.), the air gap is made as short as is practicable, thus reducing the reluctance of the magnetic circuit.

Increase of Armature Turns. To produce the necessary torque requires more armature inductors in a weak field than in a strong one, the torque being proportional to both the flux and the number of inductors (the current remaining the same). The armatures of series a.c. motors have, therefore, more ampere turns, or m.m.f., than those of d.c. motors; in fact, they are several times as strong. This m.m.f., if not corrected, would distort the field badly and produce sparking. The device for neutralizing the armature is, therefore, essential.

Neutralization of Armature M.M.F. Surrounding the armature and carried by the field magnet is a winding nearly similar to that of the armature, carrying the same current—the two being connected in series—in an opposite direction. The m.m.f. of this winding is slightly greater than that of the armature for the following purposes: *first,* neutralizing the armature m.m.f.; and *second,* producing a field in which commutation can go on satisfactorily.

Increase in Number of Poles. As the poles are weakened by the reduction in the number of turns on each, it is desirable to have as many as possible consistent with good mechanical and electrical design. The number of poles is, therefore, always greater in a.c. series motors, than in d.c. motors, the latter almost invariably having four poles.

Use of Laminated Field Cores. As the flux in the field of the motor is alternating, it is necessary to use laminated iron in all parts of the field structure which carry the flux. If this were not

done, there would be a great waste of power in eddy currents, which would also heat the motor.

Use of High-Resistance Commutator Leads. A difficulty not yet mentioned, and one of the most serious of all, is due to the fact that the coils which are, for a short time, short-circuited by the brushes are in an alternating field. They act as would the secondary of a transformer if short-circuited for the same length of time. As it is necessary to short-circuit the coils at the time of reversal of the current under the brushes, the "transformer" short-circuit current cannot be entirely eliminated by any convenient plan. The practice in this country at present is to insert high-resistance conductors, or leads, between the commutator bars and the coil. In Fig. 52 bars *b*, *c*, and *d* are shown connected by the brush and the corresponding coils short-circuited. Current flows in these coils by "transformer" action, as explained, passing through the high-resistance leads, which keep the current down to a value which will not overheat the winding. The high-resistance leads are in action only while the coils are under the brush, no current, in this case, passing out through bars *b* and *c*.

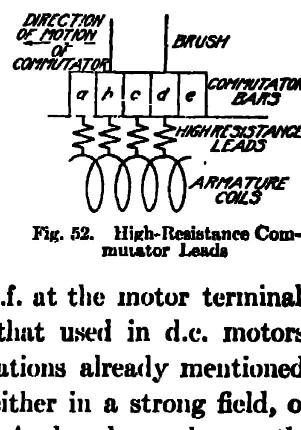


Fig. 52. High-Resistance Commutator Leads

Use of Low Motor Voltage. The e.m.f. at the motor terminals in series a.c. motors is about one-half that used in d.c. motors. This practice follows from the considerations already mentioned. A large counter-e.m.f. can be produced either in a strong field, or by many armature inductors, or both. As has been shown, the field must be weak, and while the armature inductors are numerous, it would be difficult to use enough to enable the motor to generate 500 or 600 volts. The voltage is, therefore, stepped down by means of transformers on the cars. This permits the use of high trolley voltages, which may be as high as 11,000 or more if desired.

Frequency. As frequency is one of the factors of reactance, the lower the frequency the better. The frequency is, therefore, made as low as possible, the limit being fixed by other parts of the system, such as the transformers and the generating apparatus.

CONTROLLERS

Classification. After the principles of series-motor control are mastered, the student is in a position to study the construction of control equipment. The duty of the controller is to make the connections called for in the wiring diagrams without injurious sparking at the controller contacts. There are two general forms of controller in use, namely, the cylinder and the multiple-unit types.

The cylinder, or platform, type of controller is used on cars of small or moderate size, when operated singly or with nonmotor trailers. In some special cases K, or cylinder, controllers have been used to operate motors on two cars coupled together.

In the multiple-unit type the motorman makes connections in an auxiliary circuit, thus effecting indirectly the operation of the main motor circuits. In Sprague-General Electric type M control, these main-circuit switches are operated by solenoids; in type PC the main motor controller is operated by means of an air-operated magnet valve and air cylinder. In the Westinghouse type HL the individual contactors, instead of being operated by solenoids, as in type M, are actuated by air cylinders and pistons controlled by electromagnetic valves.

CYLINDER CONTROLLER

Parts. A typical controller of the platform type is shown in Fig. 53. The principal parts are as follows: main cylinder, contact fingers, partitions, magnetic blow-outs, reversing cylinder, and enclosing case.

Main Cylinder. The main cylinder (in the center) consists of an iron drum insulated from the shaft and fitted with copper contact segments. The drum is made up of several sections insulated from each other and is rotated by the main controller handle. At the top of the drum is a notched wheel, which rotates against a roller held against it by a strong spring. The notches in this wheel coincide with the operating points and this prevents stopping on half-way points, which might cause arcing at the contacts.

Contact Fingers. The contact fingers are just at the left of the cylinder. These fingers are pressed against the cylinder con-

tacts by strong springs, and when the arc chutes are swung back into position, the fingers and contacts are enclosed in an arc-resisting box and a strong magnetic field acts to reduce arcing at contacts. Individual blow-outs and coils are used, the coils being shown between the fingers and the arc chutes, Fig. 54.

Partitions. The purpose of the set of partitions of asbestos lumber, shown next to the controller cover in Fig. 53, is to prevent the arcs from jumping from one segment to another.

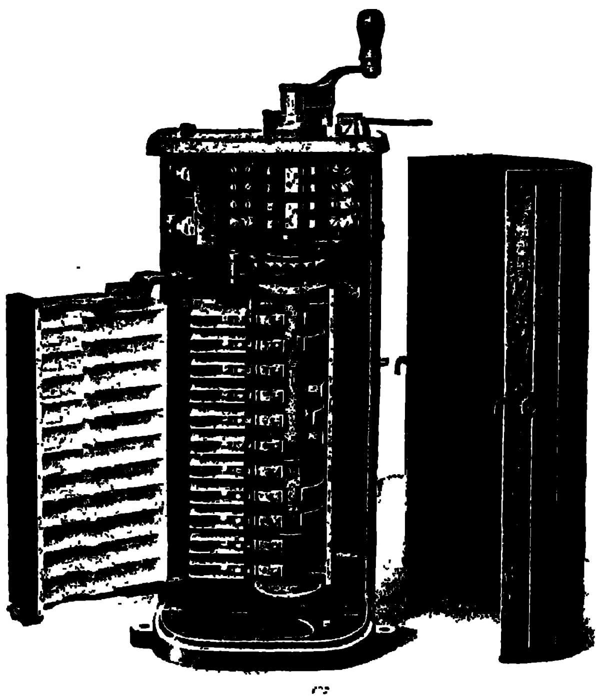


Fig 53. General Electric Type K Controller

Magnetic Blow-Outs. The magnetic blow-outs around each main finger or group of fingers are so located that the arc is blown in an outward direction. A magnetic field produces a powerful mechanical force on an arc, just as on any other conductor and instantly ruptures the arc. The magnetic blow-out construction is given in detail in Fig. 54. The coil is at the extreme right, while the magnetic pole piece is in the asbestos

insulation surrounding the finger; in the illustration the insulating cover is broken away to show the construction.

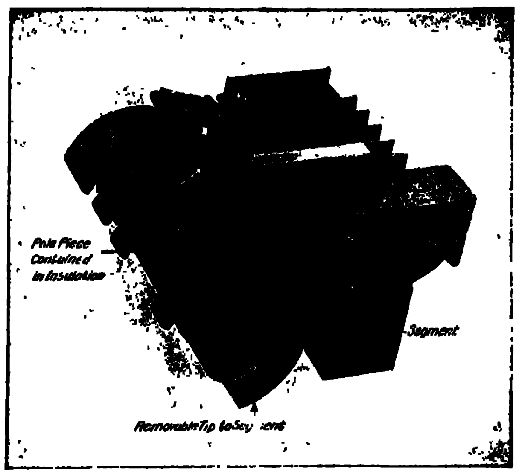


Fig. 54. Detail of Magnetic Blow-Out

Reversing Cylinder. A reversing cylinder is at the right of the main cylinder, Fig. 53. This is a wooden drum with segments for reversing the motor-armature or field circuits to change the direction of rotation of the motors. This cylinder is mechanically interlocked with the main cylinder to prevent improper operation.

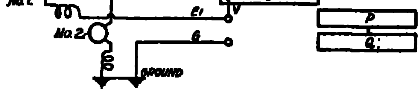


Fig. 55. Development of Controller Connections—Motors in Series

Enclosing Case. The hardwood asbestos-lined enclosing case may be easily removed for inspection.

Operation. In the operation of the controller the handle is rotated, bringing various segments under the contact fingers. Fig. 55 shows the connections in position *1*, the contact fingers

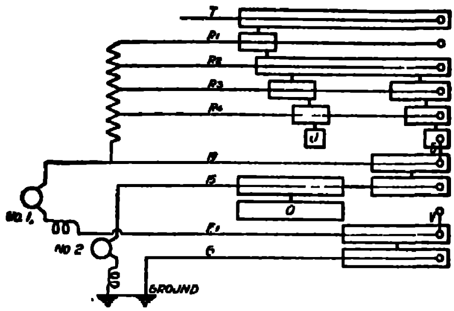


Fig 56 Development of Controller Connections Motors in Parallel

being represented by small circles. The cylinder is represented as if cut and laid out flat, or in the terms used in drawing it is *developed*. Segments *A* to *K* are not insulated from the drum, hence they are connected together by it. In this position the route of the current is as follows: trolley to segment *A;* through segment *B* and wire *R* to resistance; through motor *No. 1* to wire *E;* through insulated but connected segments *O* and *M;* through wire *15;* through motor *No. 2* to ground.

In successive positions of the controller handle the resistance is gradually cut out, then the motor connections are changed to

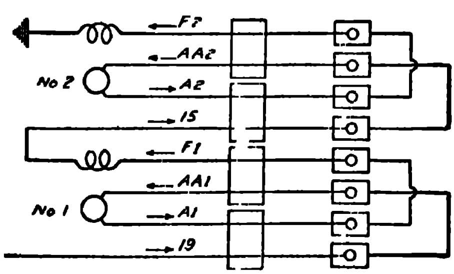


Fig 57. Forward Position of Reverse

parallel with resistance in series, next this resistance is gradually cut out, until finally the full parallel position shown in Fig. 56 is reached.

The details of the reverser connections are shown diagrammatically in Fig. 57, which represents the development of the reversing cylinder. The field coils and armatures of the two motors are shown at the left, and to the right are two sets of copper segments. In the forward position, Fig. 57, the arrows show the direction of the current, right and left alternately, beginning at the bottom. In the reverse position, Fig. 58, the current is reversed in both armatures, remaining in the same direction in the field circuits.

Explanation of Control Circuits. The student can obtain practice in reading wiring diagrams by a study of Fig. 59, which is a copy of one of the blueprints furnished with motor equipments and is explained in detail in the following paragraphs. The cables are canvas-covered bundles of wires corresponding to those shown connected to the controller fingers, Fig. 60.

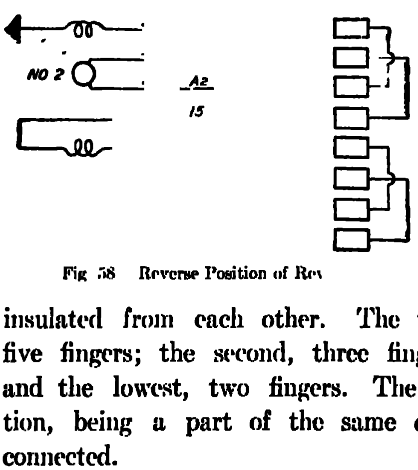


Fig. 58 Reverse Position of Rev

The type K-35 controller to be used with four motors, Fig. 59, is made up of four separate contact sections assembled on the shaft and insulated from each other. The top section has contacts for five fingers; the second, three fingers; the third, four fingers; and the lowest, two fingers. The contact rings of each section, being a part of the same casting, are electrically interconnected.

Series Circuits. Starting with controller *No. 1*, assume the handle turned to the first point. Current passes from the trolley to terminals *TT*, to controller cylinder, to terminal *R4* through resistances *R4*, *R3*, *R2*, and *R1* to terminal *R1*, to cylinder, to terminal *+1*, to cutout-switch terminal *A1–A3*, to motor terminal *A1*, through armature of *No. 1* motor to terminal *AA1*, to reverse cylinder, to contact *AA1* (forward position), to terminal *F1*, to field terminal *F1*, through motor field to *FF1*, to terminal *FF1*, to terminal *−1*, to cutout switch.

Similarly, current passes in a parallel path from terminal *+1* to *A3* through armature of *No. 3* motor to reverse cylinder *AA3*, to *F3*, through field of motor *No. 3* to terminal *FF3*, and to terminal *−1* on cutout switch.

Current passes from cutout-switch terminal *R7* to resistances *R7*, *R6*, *R5*, to controller terminal *R5*, to terminal *+2*, to cutout switch. From this point there are parallel paths, as in the first group, through the armature and

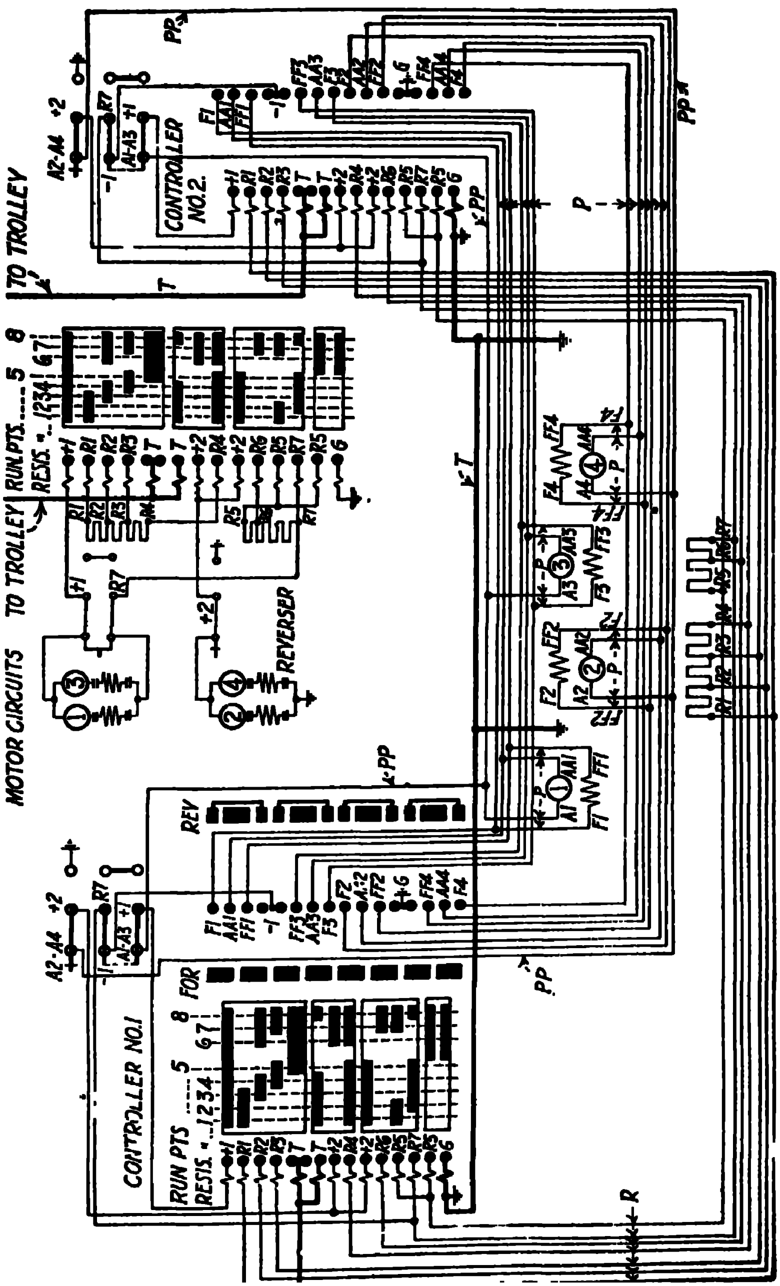


Fig. 59. Wiring Diagram for K-35 Controller

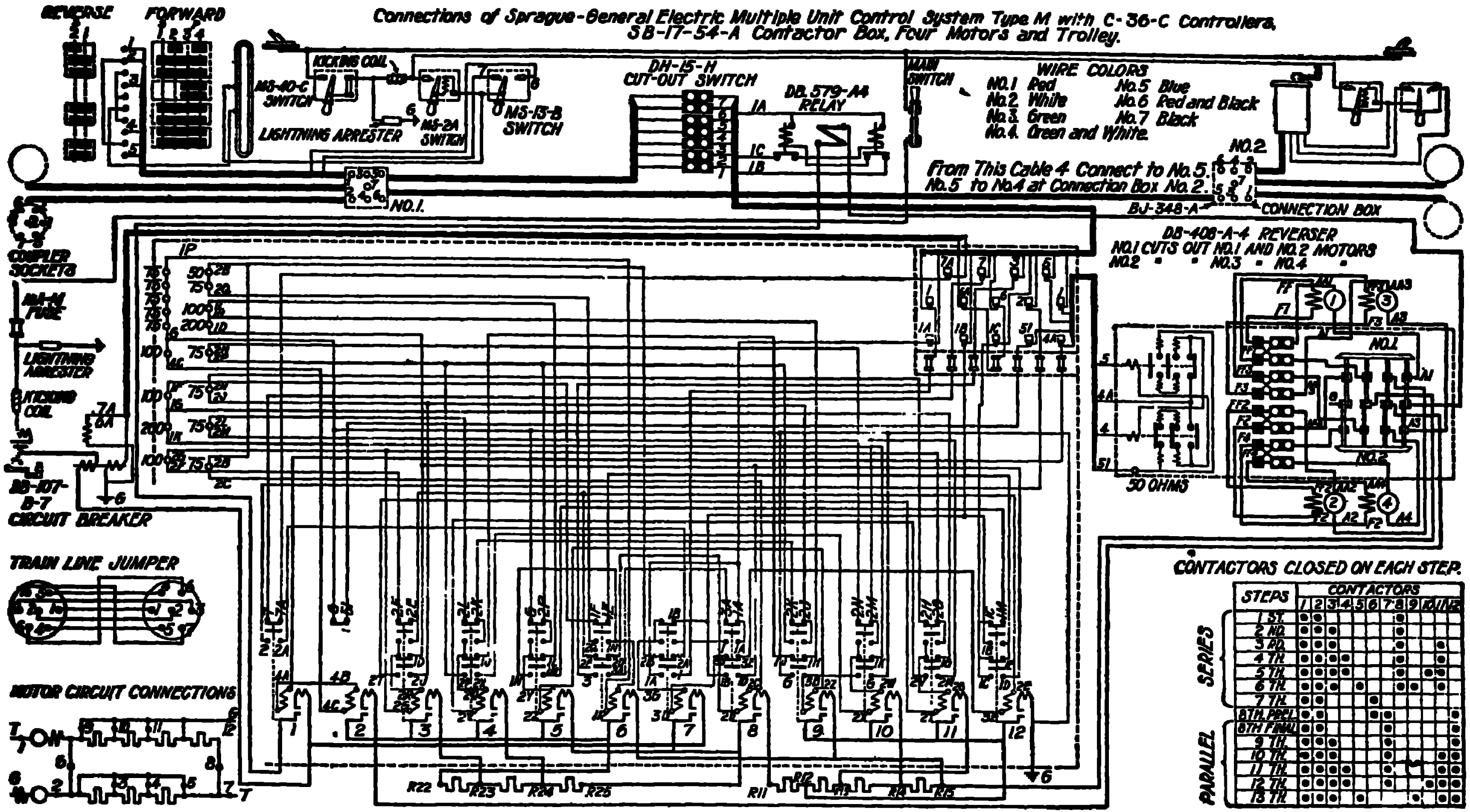


Fig. 69. Wiring Diagram for Sprague-General Electric Automatic Control

fields of motors *No. 2* and *No. 4*, both circuits passing from terminals *FF2* and *FF4* to ground.

On controller positions *2*, *3*, *4*, and *5*, resistance is cut out, so that the two pairs of motors are operating in series without resistance on position *5*, or first running point. This may be more clearly seen in the simplified diagram in the top center of Fig. 59.

Transition. Transition is the preparatory step to passing from series to parallel position. This takes place between controller points *5* and *6*. Current momentarily passes through motors *No. 1* and *No. 3* to *R7*. Here it divides, one path being through *R7*, *R6*, and *R5* to ground and the other through motors *No. 2* and *No. 4* to ground. This connection insures continuous torque during the change of connections from series to parallel.

Parallel Circuits. On controller point *6* current passes from *T* to *+1*, to cutout switch, to *A1* and *A3*, through motors *No. 1* and *No. 3* in parallel to *R7*, *R6*, and *R5*, and to ground. A parallel circuit is completed on this point from *T'* to *R2* through resistances *R2*, *R3*, and *R4* through terminal *+2*, thence to motors *No. 2* and *No. 4* in parallel to ground.

Position *7* cuts out a portion of the resistance in series with each pair of motors, and position *8* cuts out the remainder. Position *8* is the second running position, the four motors running in parallel without resistance.

Reverse. When the reverse cylinder is thrown to *Reverse*, the direction of current through the motor fields is reversed, thus changing the direction of rotation of the motors.

Transition. Type K controllers effect the change from series to parallel connections of motors without cutting off power from both motors on a two-motor equipment or both pairs of motors on a four-motor equipment, thus permitting a smooth acceleration.

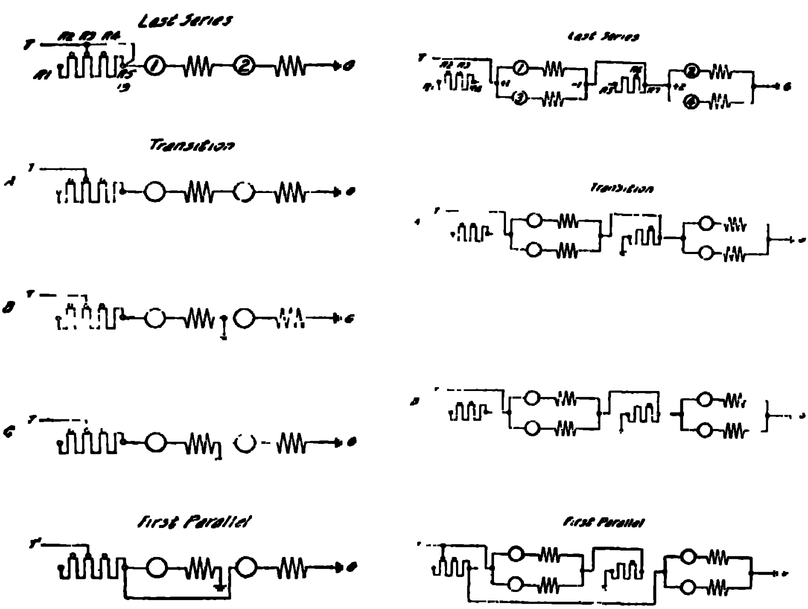
With controllers for small motors the transfer of connections from series to parallel is effected by the K method, which consists of first grounding the low side of the first motor or pair of motors and opening the circuit of the second motor or pair and then connecting the second motor or pair in parallel with the first.

With larger controllers the bridge method of transfer was originally used. This method, however, has been superseded by the T, or shunt-resistance, method, which gives substantially the same smoothness as the bridge method and with far less burning of the contacts. It has, therefore, been adopted for large K controllers, as well as for Sprague-General Electric multiple-unit control. Diagrams showing the steps in transition in the K and T methods are given in Fig. 61.

MULTIPLE-UNIT CONTROLLER

Multiple-Unit vs. Manual Controller. The multiple-unit controller differs from the manual controller in that the motor con-

nections as shown in the diagrams are made by circuit-breakers which can open circuits carrying very heavy currents. A second very important feature of this system, as the name indicates, is the operation of all of the motors in a train from one point. A



Small Drum Controllers Large Drum Controllers

Fig. 61. Transition Connections

third advantage is the ease with which the accelerating current, which is always much larger than the running current, can be limited. The principal systems of control in use in this country are described in the following pages.

Sprague-General Electric Type M Control

Extent of Use. The original multiple-unit control system known as the Sprague-General Electric type M has been used for many years, and consequently there are large numbers of these equipments in operation. It is therefore important that the student familiarize himself with the fundamental principles of the operation of the system. It should be noted, however, that in recent years the General Electric Company has made a most thorough study of control equipments for single-car and train

operation and as a result has developed what is known as type PC control, which embodies all the operating capabilities of type M and avoids former troubles due to improper functioning of independently operated contactors; interlocks on individual contactors; avoids complicated control circuits; reduces weight; and contains many mechanical improvements. Because of these advantages and because it can perform the same duties as type M, PC control now practically supersedes type M except for heavy locomotive equipments and a few special cases. The cam-operated type, as PC is called, can be used in the same train with type M operating from the same master controller.

General Description. In the manual controller the contacts are made between contact fingers and segments on the drum. Each finger and its accompanying segment constitute a switch which is opened and closed by the rotation of the controller handle. The controller illustrated in Fig. 53 contains eleven such switches. If these simple and crude switches are replaced by modern circuit-breakers, operated by solenoids carrying small control currents, there results one of the essential features of the Sprague-General Electric type M control. Before taking up a study of the circuits in this system, it is desirable to become acquainted with the appearance and the purpose of each of the component pieces of the equipment. Reference to Fig. 60, regardless of the wiring, shows that the devices described in the following paragraphs are used.

Contactors. The circuit-breakers in the form especially developed for traction work are called contactors. Such a contactor is shown in Figs. 62 and 63. It consists of a coil of fine wire surrounding a movable plunger and capable of exerting a powerful pull thereon. The lower end of the plunger is attached to a switch arm, on the end of which is a copper contact finger which is one end of the circuit. When the solenoid is energized, the contact piece is pulled into firm contact with a stationary finger which forms the other terminal of the circuit, and the main circuit is thus closed. When no current flows in the coil, a spring restores the switch arm to its original position, thus opening the main switch. The circuit-breaking contacts are enclosed in a chamber of fire-resisting material of the form shown, thus confin-

ing the burning action of the arc to the renewable contact fingers. The arc is extinguished by the magnetic blow-out principle already described. A small coil is located just above the contact fingers but separated from them by a fireproof partition. This coil is horizontal, and it lies just back of the terminal block shown in Fig. 63. Its poles are extended by two iron strips, one on each side of the fireproof chamber. One of these pole strips appears in the illustration. The magnetic blow-out field exists between the two poles in a horizontal direction. The several contactors comprising the equipment of a car are placed in a sheet-iron box, which is accessibly located under the car, Fig. 64.

Fig. 62. Sprague-General Electric Contactor

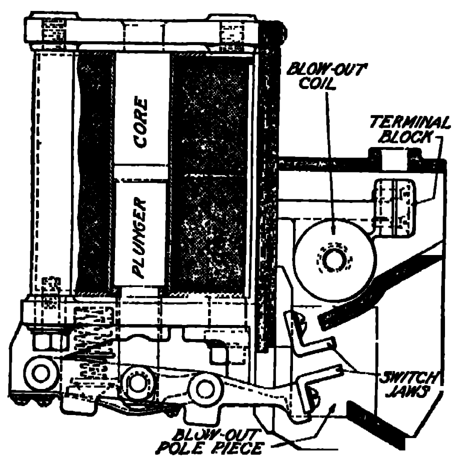


Fig. 63. Sprague-General Electric Contactor Diagram

Interlocks, or Auxiliary Contacts. It will be noted that above several of the contactors in Fig. 60 are located small auxiliary contacts in the control circuit. These are operated by the motion of the contactor, as shown diagrammatically in Fig. 65, and correspond to the interlocks on contactor *2*. The auxiliary contact switch consists of the stationary terminals and a movable stem attached at one end to the contactor lever. The stem carries one or more insulated copper contact disks. In Fig. 65 the contactor is shown open and auxiliary circuit *1* closed. When the contactor closes by means of the current sent

through its operating coil, auxiliary circuit *1* is opened and *2* is closed. In this manner any number of auxiliary circuits can be controlled.

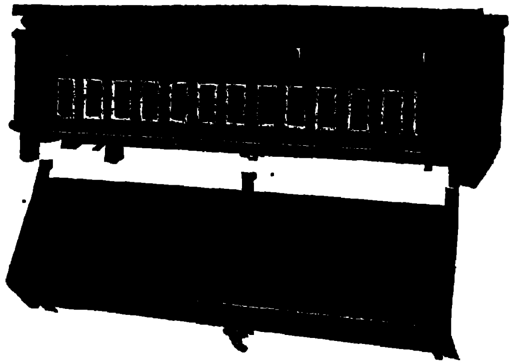


Fig. 64. Group of Sprague-General Electric Unit Switches

Control-Circuit Cutout Switch. The control-circuit cutout switch is a simple cylindrical switch with a row of segments and contact fingers. The rotation of this cylinder opens and closes all the control circuits at one time.

Main Circuit-Breaker. The main circuit-breaker is a modification of the type used on station switchboards. In the latter there is a switch opened by a spring, the contacts being located in a blow-out field. The switch is held closed by a trigger, which is tripped by a solenoid carrying all or part of the line current. The circuit-breaker may be closed by hand. In the car circuit-breaker shown diagrammatically in Fig. 60, the setting of the switch is done by means of a solenoid, represented vertically. The breaker may be tripped either by the heavy-wire horizontal coil in the main circuit or by the fine-wire horizontal coil in the control circuit. The left-hand heavy-wire horizontal coil furnishes the magnetic blow-out field.

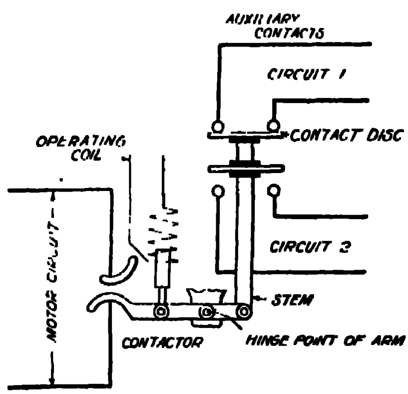


Fig. 65 Diagram of Sprague-General Electric Interlock

Reverser. The reversing cylinder of the manual controller is replaced by a device known as the reverser, Fig. 66, which operates on exactly the same principle. The difference is that, whereas the cylinder is rotated by hand, the reverser is rocked by two solenoids, one acting in each direction.

Master Controller. The current for operating the contactors comes from the trolley wire and is distributed to the several solenoids at the proper instants through a master controller similar to that illustrated in Fig. 67. This contains a drum similar in construction to the main drum of a cylinder controller, but much smaller in diameter as the currents to be carried are

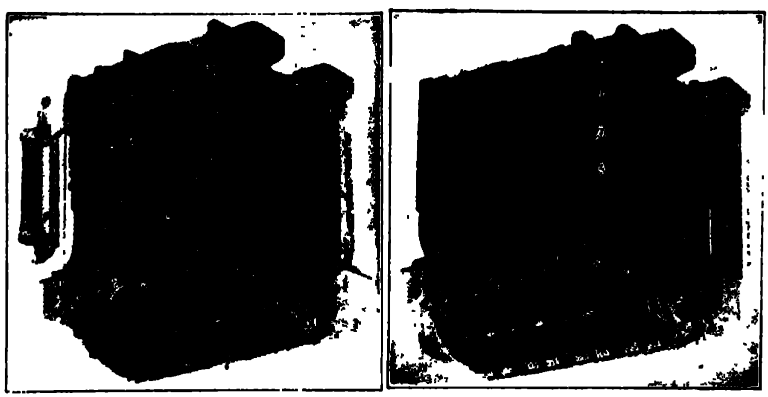


Fig. 66. Front and Back View of Sprague-General Electric Reverser

small. The segments and contact fingers are of the standard form. This master controller operates the contactors and the reversers.

Train Line. The control current is carried in a bundle of wires or cables known as the *train line* because it passes from one motor car to another, connecting all the switch groups or sets of contactors in the train. The train line terminates at each end of each car in coupler sockets, which are bridged across between cars by flexible couplers.

Nonautomatic Control. The vital features of the nonautomatic multiple-unit control are not essentially different from those of the cylinder control. If the student will keep this fact clearly

in mind and will remember that the rather considerable number of wires which he sees in the diagram belong mostly to the control circuits, he should not find any great difficulty in following the connections. The connections will be followed step by step, for in no other way can the diagram teach the lessons which should be learned from it.

Motor Circuits. In Fig. 60 the control circuits are shown by light lines, and the motor circuits by heavy lines. The twelve contactors are shown in a row in the lower part of the diagram and numbered consecutively from *1* to *12*. By means of them the connections are made, as in the small diagram and the contactor table, both of which are in the lower right-hand corner. The diagram is for a four-motor equipment, but as each pair of motors can be treated as a single motor—the motors of the pair being connected permanently in parallel—but two motors are shown in the small diagram. The contactor table enables one to determine at a glance which contactors are closed at each of the ten master-controller positions. There are twelve vertical and ten horizontal columns in the table. By reading horizontally along any line corresponding to a controller step, the number of the contactors in operation is determined by the positions of the dots. For example, on step *1*, contactors *1*, *2*, and *8* are closed, etc. The motor-circuit diagram shows the locations of the various contactors in the motor circuits. The locations are as follows:

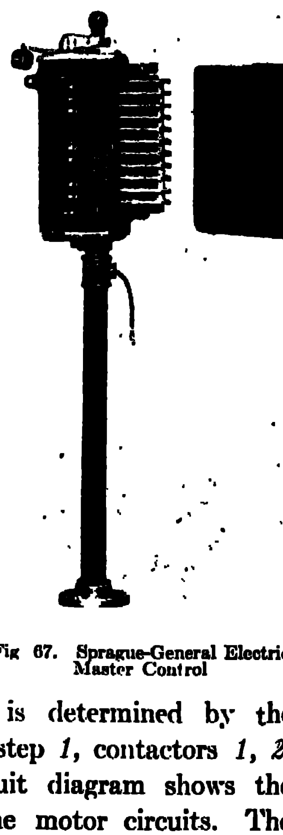


Fig 67. Sprague-General Electric Master Control

(1) Between trolley *T* and one motor (or pair of motors).
(2) Between the second motor and the resistance grids.
(3) In the jumper, or short-circuiting wire, around the first resistance grid.
(4) In the jumper around the second resistance grid.
(5) In the jumper around the three lower resistance grids.

(6) In the bridge connection between the two motor circuits.
(7) In the trolley circuit of the lower motor.
(8) In the wire connecting the two sets of resistance grids.
(9) Same as (5), but for the upper grids.
(10) Same as (4), but for the upper grids.
(11) Same as (3), but for the upper grids.
(12) In the ground circuit of the upper motor.

The combinations shown in the contactor table produce the following connections:

Step 1. Trolley—motor *No. 1*—all resistance grids—motor *No. 2*—ground.

Step 2. Trolley—motor *No. 1*—upper four resistance grids—motor *No. 2*—ground.

Step 3. Trolley—motor *No. 1*—three sections of upper grids—motor *No. 2*—ground.

Step 4. Trolley—motor *No. 1*—two sections of upper grids—motor *No. 2*—ground*.

Step 5. Trolley—motor *No. 1*—one section of upper grids—motor *No. 2*—ground.

Step 6. Trolley—motor *No. 1*—motor *No. 2*—ground. This is the series, or low-speed, running position, each motor having half voltage.

Step 7. Trolley (lower-right-hand corner)—lower resistance grids—motor *No. 2*—ground.

Trolley (upper left hand corner)—three sections of upper resistance grids—ground.

Step 8. Same, but with one grid cut out in each motor circuit.

Step 9. Same, but with another grid cut out in each motor circuit.

Step 10. Motors in parallel with no resistance in circuit. This is the parallel, or high-speed, running position, each motor having full voltage.

Passing next to the motor circuits in the main diagram, shown by heavy lines, the foregoing combinations should be traced out step by step. In order to make sure that the student understands the meaning of the several pieces of apparatus shown in these circuits, one of the combinations is followed through.

The current comes from the trolley shown at the top through the main switch and the fuse to the kicking coil. This is a coil of low resistance, but like all coiled circuits, it opposes to lightning discharges a strong counter-e.m.f., forcing them to go through the

* The student will naturally inquire why in positions *3* and *4* he finds contactors *3* and *4* closed when the grids which they short-circuit are already short-circuited by *5*. The reason for this is that the operating coils of *3* and *11*, and *4* and *10* are permanently connected in series as they operate together in the parallel position of the controller. No harm is done by allowing them to close in the series position, and the wiring is simplified by the arrangement.

lightning arrester to the ground. From the kicking coil the current passes through the circuit-breaker and through contactor *1*. The route from here on is determined by the controller position, but to this point it is the same for all positions. Take step *1*. From contactor *1* the current goes through the following circuits: center of motor-cutout switch, branching to the armatures of the two motors forming a pair; from the armatures through the reverse to the corresponding field windings; back to the motor-cutout switch; to the right-hand end of the resistance grids; through contactor *8* to the left-hand group of resistance grids; through contactor *2* to the motor-cutout switch again; through the armatures and fields of the other pair of motors; to the ground. This corresponds exactly to the circuit previously traced out for step *1*.

Some additional explanation of the cutout switch and the reverser connections may be helpful before going farther. The cutout switch is a double four-pole switch, the upper and lower parts each controlling two motors. By opening one or the other of the switches the corresponding two motors can be cut out of service, and the car can be operated in an emergency by the others. This arrangement is also convenient in testing. As has been explained, the function of the reverser is to reverse the direction of the current in the field or armature windings but not in both. In this case the field terminals are the ones reversed.

In a manner similar to the foregoing, the student should follow through the several combinations of motor circuits corresponding to the other nine controller steps.

Control Circuits. In the upper left-hand corner of Fig. 60 is shown the developed diagram of the master controller. The steps are represented by the vertical dotted lines. At each step the corresponding dotted line is considered as brought under the row of controller fingers at the left.

On step *1* the control current takes the following route: trolley; switch and fuse, beyond which is a lightning path to ground through the lightning arrester; kicking coil; master-controller switch; magnetic blow-out in master controller; upper four fingers on controller; reverser switch, which may be assumed to be pushed to the left; by wire *8*, which goes into the cable

emerging at terminal board *1;* thence to the cutout switch; then to the main connection-board terminal *0;* cable and wire *8* and to the upper reverser operating coil. From the reverser coil—which, as the name indicates, throws the reverser over to the corresponding position—the path is through the reverser interlock, at the right of the reverser coil, by way of wire *8A* to the operating coil of contactor *1;* thence by wire *8B* to the operating coil of contactor *2;* thence by wire *8C* to the resistance coils; thence by *8D* to the operating coil of contactor *8;* thence by *8E* through the interlock on contactor *12*—making it impossible for *12* and *8* to be closed at the same time as they would practically make a short-circuit if both closed at once—through wire *1* to the master controller and to ground.

In following this route the student will have noted that the wires are plainly lettered and numbered so that with a little practice there is no danger of confusion. The wire has the same number over practically the entire route, the letter changing as the circuit passes through each piece of apparatus.

On step *1* of the master controller there are several auxiliary operations with which the student should be familiar.

To the right of the master-controller switch is represented the switch which is used to set and trip the main circuit-breaker, shown in the lower left-hand corner. The circuit-breaker contains four windings: (1) the upper horizontal heavy-wire coil, the blow-out coil; (2) the lower heavy-wire coil, which opens the breaker on overload; (3) the vertical fine-wire coil, which sets the breaker; and (4) the horizontal fine-wire coil, provided for hand-tripping the breaker. When the circuit-breaker operating switch is thrown to the left, it energizes the setting coil on the breaker by way of wire *7* through the interlock on contactor *2*, wire *7A*, setting coil on breaker, and ground. When the switch is thrown to the right, it trips the breaker through wire *10*, tripping coil, breaker, and ground.

A second point to be noted is that when the reverser has operated by means of current sent through its operating coil, its interlock breaks the connection between wires *8* and *8A* and establishes a new connection between *8* and *81* and by way of the interlock on contactor *1* and wire *82* to ground. This is the

holding position of the reverser, in which a small current is sufficient to hold the arm in place.

The student should now follow through the control circuits on the other steps, noting particularly the action of the interlocks in preventing two circuits from being energized at the same time when trouble would be caused if the circuits were not so protected.

Automatic Control. As was stated earlier, one of the great advantages of the multiple-unit system is that control of acceleration can be arranged without great difficulty. Such control is beneficial in several ways: (1) by limiting the starting current the strain on the motors is kept within a reasonable amount; (2) the corresponding demand for current from the power house and line is reduced; (3) and the acceleration of the car is rendered uniform, ensuring the comfort of the passengers when the car starts.

Fig. 68. Sprague-General Electric Current-Limit Relay

The fundamental principle of automatic control is that automatic means are provided for limiting the amount of current which can be drawn from the line. This is accomplished by a current-limit relay of the general form shown in Fig. 68. The relay has two windings, one a fine-wire coil in the control circuit and the other a heavy copper-strap winding of a few turns in the main motor circuit. Below is an interlock of the kind already described, and above is a small cylinder and a piston, known as a dashpot, which retards the upward motion of the plunger of the relay.

A wiring diagram for a modern automatic control is shown in Fig. 69. It is not very different from the preceding system and will not be followed through in detail. The number of contacts and the combinations of motor circuits produced by them are the same as in the preceding case. There are, however, more gradual resistance steps. These motor circuits can be followed from the motor-circuit diagram in connection with the contactor table. The master controller is somewhat different from that pre-

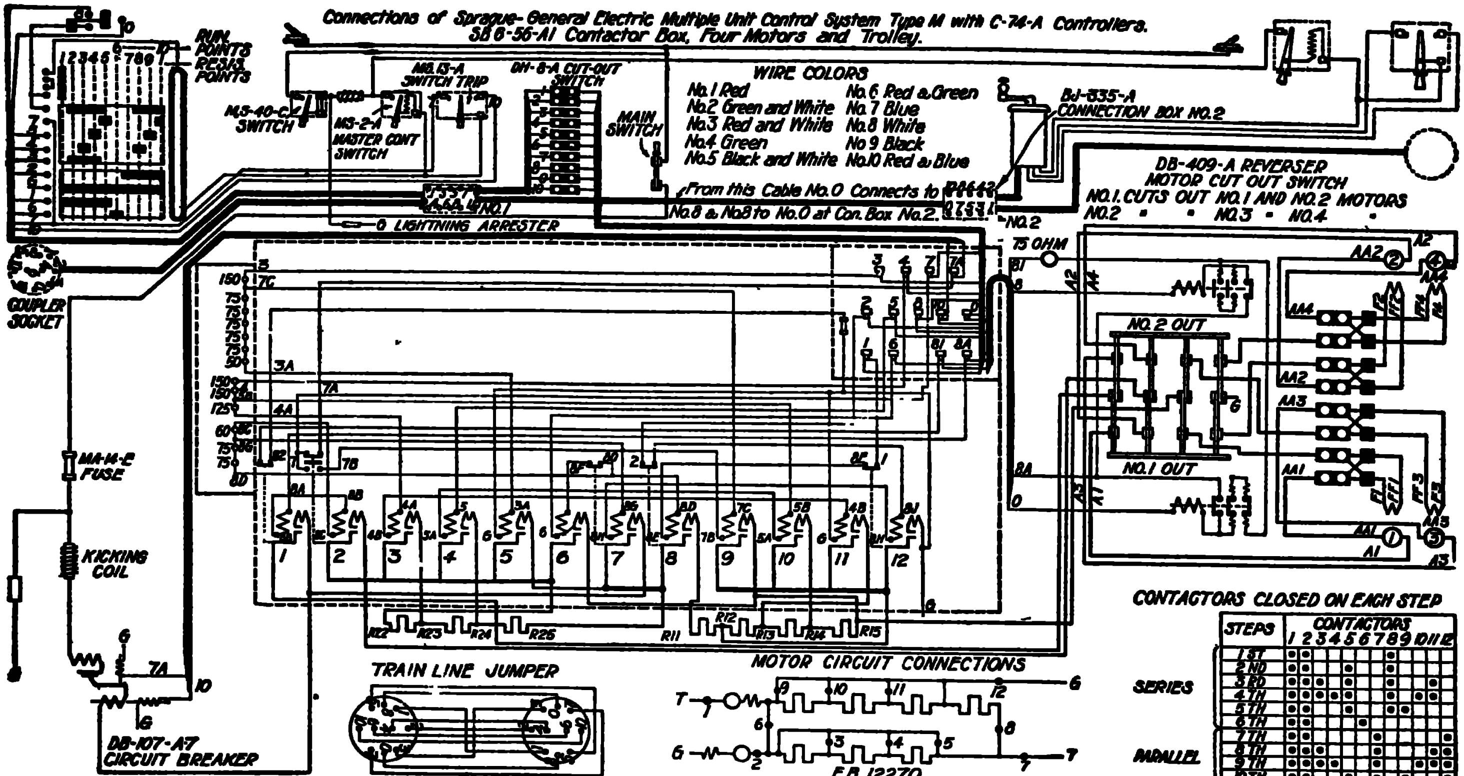


Fig. 60. Wiring Diagram for Sprague General Electric Nonautomatic Control

viously described, in that the reverse direction of the reverser is secured by a motion of the master-controller handle in the opposite direction from that which produces forward motion. The diagram shows four forward positions of the master controller—two each on series and on parallel—and two reverse positions.

Interlock Principle. Much greater use of the interlock principle is made in automatic control, and it is upon this feature that the student should concentrate particular attention. Most of the auxiliary switches used have four pairs of contacts, the purposes of which will be explained. The number of these at first

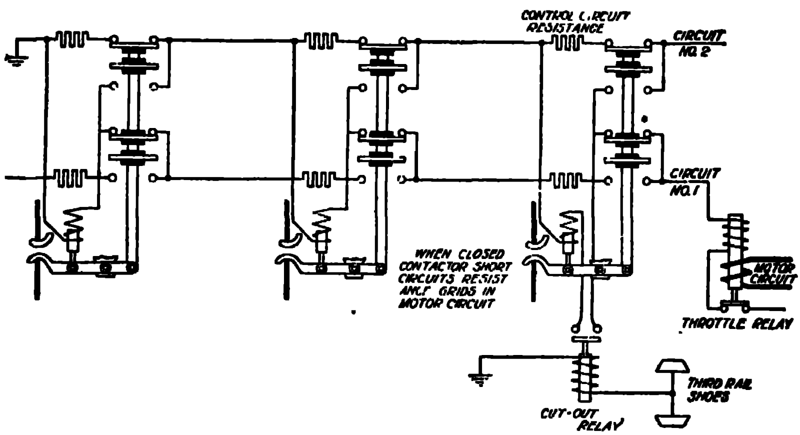


Fig. 70. Diagram of Interlocks, Sprague-General Electric Automatic Control

appears confusing, but as the same general principle underlies the operation of them all, this complexity is only apparent.

The operating principle of automatic acceleration will be studied with the aid of Fig. 70. In this illustration are represented three contactors, each with four pairs of auxiliary contacts. These contactors, when closed, cut out sections of resistance grids and thus increase the current in the motor circuit. These contactors are intended to close automatically one after the other, with sufficient intervals between to allow the increasing counter-e.m.f. of the motors to keep down the current. This is as if a motorman, in rotating an ordinary cylinder-controller handle, were compelled to wait on each notch until the current fell to a predetermined value.

The purpose is accomplished by means of the throttle relay and the interlocks. The throttle relay has, as shown in Fig. 70, two windings, one in the main motor circuit and one in the control circuit. The current in the control-circuit coil cannot open the relay alone, but when the motor current rises above a predetermined amount, the relay opens. In the illustration parts of two of the control circuits are shown. These wires are connected to the trolley through the master controller. Either of them may, therefore, supply current when connected to the ground. With the conditions as shown in Fig. 70 current passes from wire *2* through the auxiliary switches and the control resistance coils. If the motor current is not sufficient to open the throttle relay, current passes from wire *1* through the throttle relay, the auxiliary contacts, the cut-off relay (closed whenever the third-rail shoes are alive), the operating coil of the right-hand contactor, and the control-circuit resistance coils to ground. The contactor closes and short-circuits a motor-circuit resistance grid and, presumably, increases the motor current sufficiently to open the throttle relay. As long as the throttle relay remains open, no more resistance can be cut out as the next contactor cannot close. As soon as the motor current falls again to the proper value, the throttle relay closes and the second contactor automatically goes through the same operations as the first. Any number of resistance contactors can be operated on this principle. From the functions performed by control circuits *1* and *2* they are called the *accelerating* circuits, *1* being the *lifting* circuit and *2* the *holding* circuit. The reason for the use of the words "holding" and "lifting" is apparent from the fact that current through *1* closes the contactors and through *2* holds them closed.

The automatic feature just described is the main difference between this type of control and the one discussed in detail. With the fundamental principle thoroughly understood, the student will be able to trace out the circuits if necessary for his practical work. For those who wish practice in tracing Fig. 69 is given.

Sprague-General Electric Type PC Control

General Description. In the type PC control the several contactor units are compactly grouped and instead of each being

actuated by its individual solenoid, a camshaft is provided, with a cam for each contactor, and the shaft is rotated by a rack and pinion driven by an air engine. This group is called the motor controller, and magnet valves for controlling the air engine are operated by means of a master controller, as with type M. By means of the cam-operated group a definite sequence of connections is insured without the possibility of improper functioning which sometimes occurs when each contactor is independently operated. Disc interlocks on individual contactors are also eliminated, the automatic current-limit control being effected by checking the rotation of the camshaft.

Operation. An important operating feature is the arrangement of contactor arc chutes; they are assembled in a single group, which can be swung downward, exposing all parts of the contactors. In Fig. 71 is shown the arrangement of a typical 600-volt four-motor equipment. Current enters the car through the trolley, passing through the main switch to the motor controller. Control current is taken from the live side of this switch through a control switch near each master controller, passing to the train-line cable and the motor controller. The connections for a four-motor controller are given in Fig. 72. On step *1*, as is noted in the table, the line breaker is closed with all resistance in circuit and two motors in series and two in parallel. On steps *2*, *3*, and *4* resistance is short-circuited, and step *5* is the series running position. The transition occurs between steps *5* and *6*, after which resistance is again short-circuited to the full parallel position step *9*.

Motor and Master Controllers. The main, or line switch is of the circuit-breaker type and is capable of interrupting the full-load current of the car. This breaker is actuated by an individual air-pressure-controlled magnet valve and air cylinder. The reverser is also supplied with an individual air cylinder and magnet valve. The contactor-group camshaft is operated by a cylinder with a double piston shown in section in Fig. 73. Magnet valves actuated by moving the master controller admit air or allow it to exhaust from the cylinder. The illustration shows the position of the valves and pistons when the controllers are in the *OFF* position. It may be seen that air pressure is applied from the reser-

voir through the *OFF* valve, while the *ON* valve allows air to exhaust to the atmosphere. When the master controller is turned to the first point, the reverser operates, the line breaker closes, and both the *ON* and *OFF* magnet valves are energized, moving

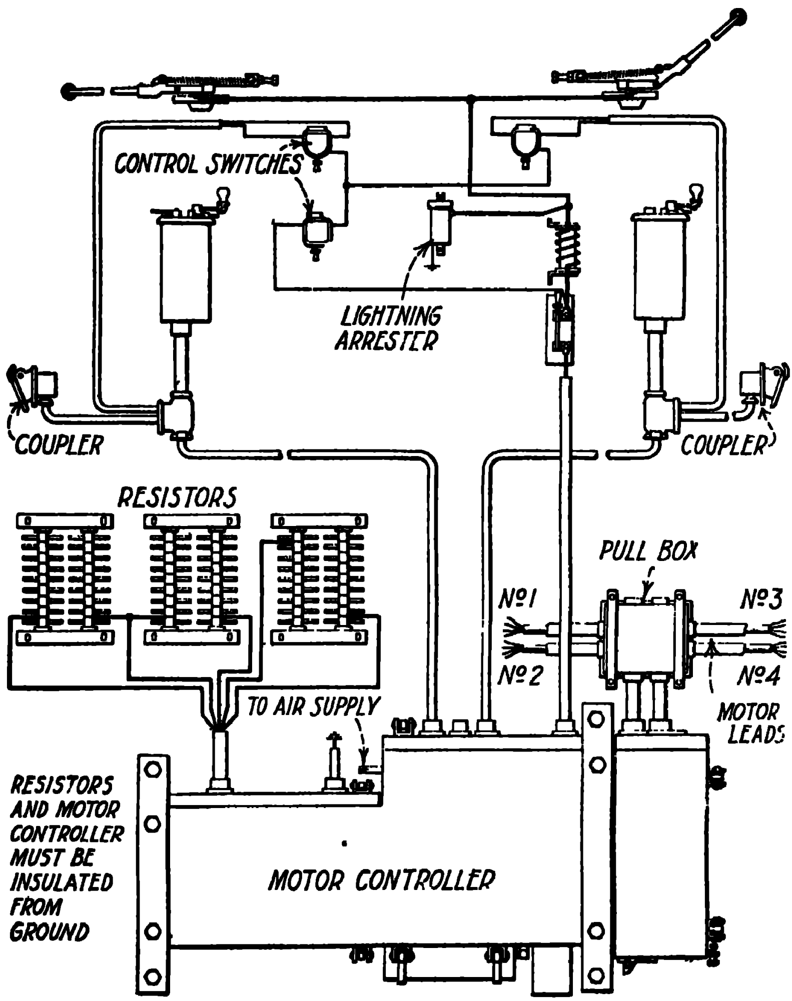


Fig. 71. Arrangement of Car Equipment with Type PC-5 Controller

to the up position. This applies pressure to the *ON* piston and allows air to exhaust from the *OFF* cylinder. The rack rotates the camshaft until the *OFF* magnet valve is de-energized. This applies air pressure to the *OFF* cylinder, the piston is balanced

between the two pressures, and the camshaft stands at the first operating position of the motor controller. The succeeding posi-

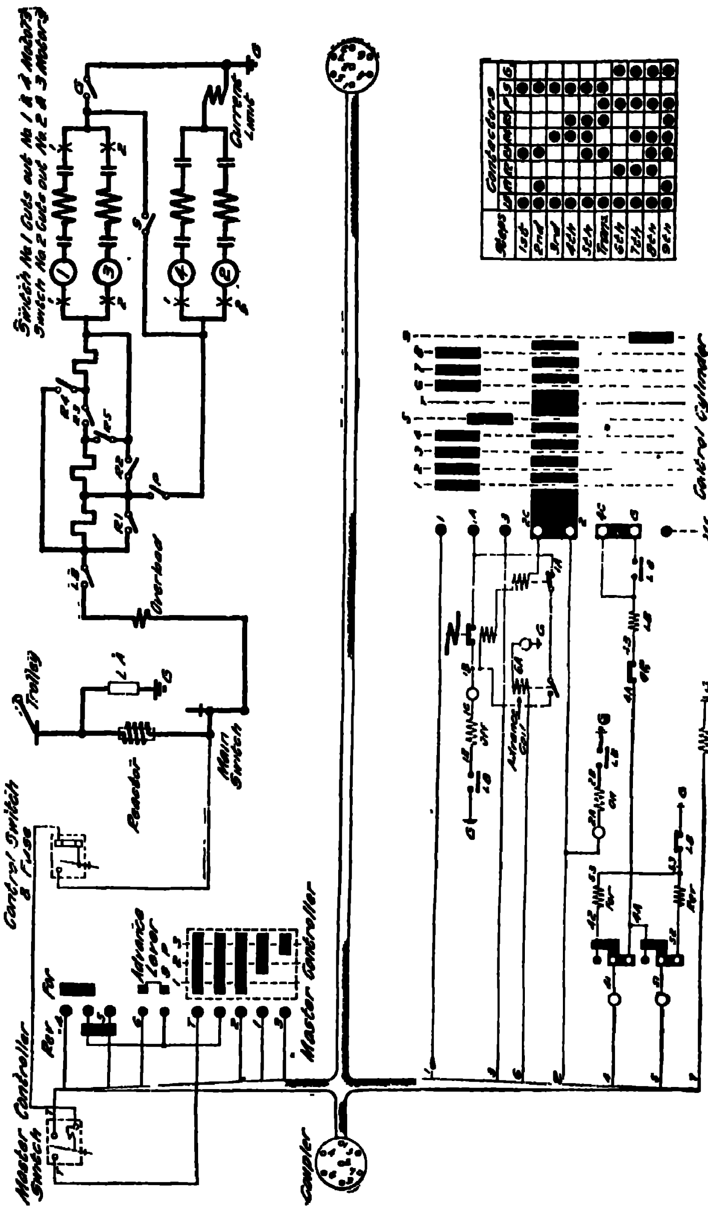


Fig. 72. Connections of PC-5 Controller and Four Motors

tions of the motor controller are obtained by alternately energizing and de-energizing the *OFF* magnet valve. When the master con-

troller is turned off, both valves are de-energized and the rack moves the pinion and camshaft to the *OFF* position.

Automatic Feature. With non-automatic control each point on the master controller indicates a corresponding position of the motor controller. When automatic control is used, however, the master controller operates the reverser and the line breaker and causes the rotation of the camshaft for the first step. The camshaft then automatically moves to succeeding positions but is checked in case of excessive current, by the current-limit relay connected as shown in Fig. 72, until the current falls to a predetermined value. This relay has a series coil carrying the motor current, and too rapid acceleration causes the relay contacts to open, arresting the progress of the camshaft until the current drops. To allow a greater accelerating current in emergency, a

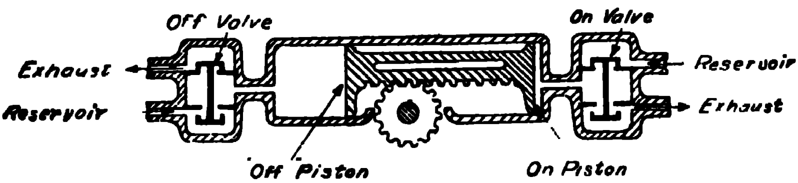


Fig 73 Cross-Section of Operating Cylinder, Piston and Guides

notching relay is used, by means of which the motor controller can be advanced one point at a time without regard to the current-limit relay.

Westinghouse Unit-Switch Control

Characteristic Features. The Westinghouse Company has developed a system of multiple-unit control which is, in many ways, similar to the Sprague-General Electric system. An essential difference is that the energy for operating the unit switches is supplied by means of compressed air instead of the electric current. This involves many differences in detail. The compressed air is controlled by electropneumatic valves, current for these being supplied through a train line, as in the previous case. The essential parts of the system may be summarized as follows:

(1) A group of unit switches or circuit-breakers operated (through electropneumatic valves) by compressed air, which in turn is operated by

means of a multiple-wire control circuit (as in the Sprague-General Electric control).

(2) A train line and set of control circuits, with a master controller by means of which the operating coils of the electropneumatic valves are energized in the proper combinations by current drawn from the third-rail shoes.

(3) A piping and reservoir system by means of which the unit switches and reservoir are operated.

The remaining parts are not essentially different from those of the other system.

Unit Switch. The unit switch is shown in cross-section in Fig. 74. Compressed air enters through the pipe shown in section

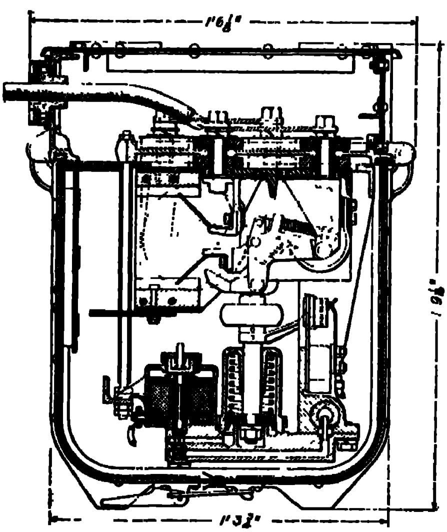


Fig. 74 Cross-Section of Westinghouse Unit Switch

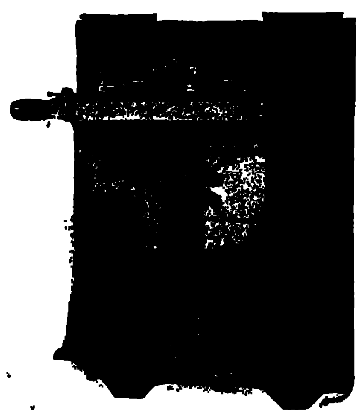


Fig. 75. View of Westinghouse No. 4 Unit Switch

in the lower right-hand corner and passes to the valve through the small passage. When the coil of the valve is energized, the air is allowed to enter at the bottom of the cylinder and it pushes the piston upward against the resistance of the coiled spring and closes the switch. When the exciting circuit is opened, the supply of air is cut off and the air in the cylinder is allowed to escape; the switch is then opened by the spring. The arc is broken in a magnetic field produced by a magnet, the end of which is shown dotted in the illustration. Fig. 75 is a picture of the unit switch with the sides of the box, the arc chute, the cylinder, and the valve cut away to show the working parts. Figs. 74 and 75,

taken together, should give a clear idea of the operation of the valve. An enlarged view of the cylinder and magnet valve in Fig. 75 is given in Fig. 76. Details of the blow-out coil are shown

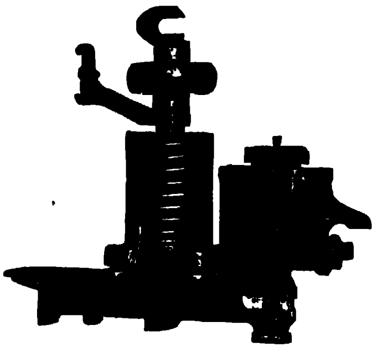


Fig. 76. Westinghouse Unit-Switch Cylinder and Magnet Valve

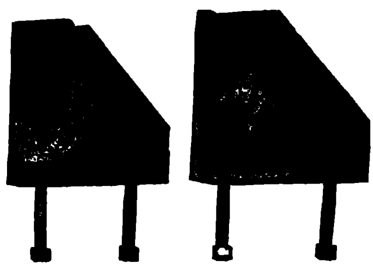


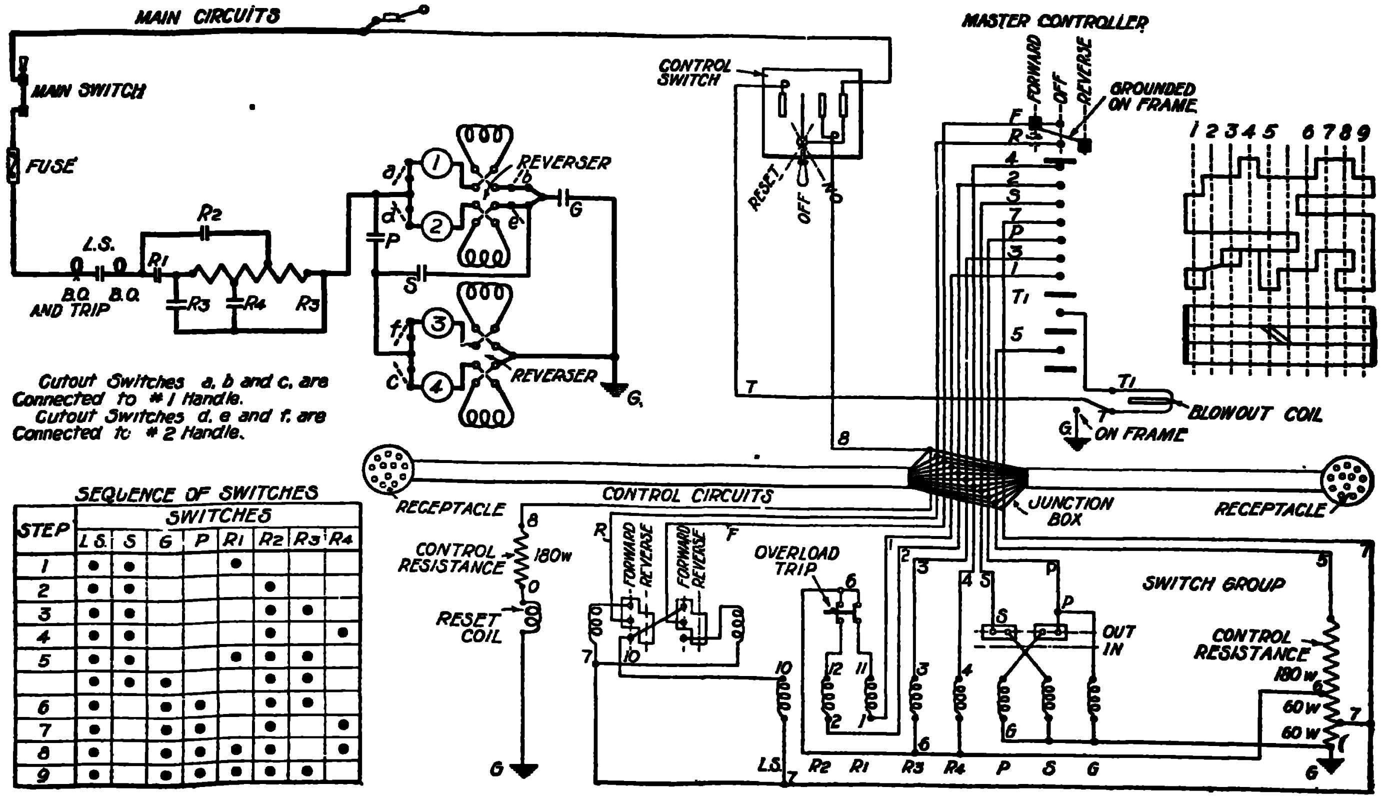
Fig. 77. Details of Blow-Out Coil, Westinghouse Unit-Switch

in Fig. 77. The appearance of the switch group is given in Fig. 78.

Control and Motor Circuits. The control and motor circuits are shown in simplified form in Fig. 79. The main circuits are in the upper left-hand corner, and the control circuits are in the

Fig. 78. Group of Unit Switches, Westinghouse System

lower right-hand corner. In the lower left-hand corner is a table showing the sequence of switches corresponding to the several series and parallel positions. For simplicity, the operating coils



SEQUENCE OF SWITCHES

STEP	L.S.	S	G	P	R1	R2	R3	R4
1	●	●			●			
2	●	●				●		
3	●	●				●	●	
4	●	●				●		●
5	●	●			●	●	●	
	●	●	●			●	●	
6	●		●	●		●	●	
7	●		●	●		●		●
8	●		●	●	●	●		●
9	●		●	●	●	●	●	

Fig 79 Wiring Diagram, Westinghouse Multiple-Unit System

of the unit switches are separated from the corresponding contact fingers. They may readily be identified by the designating letters and figures. As the details are the same as in the Sprague-General Electric system, the student will be able to trace out the circuits without further assistance, referring to the previous explanations if necessary.

Air Supply. As all cars large enough to warrant the use of the multiple-unit system are also provided with air brakes, there is ample air supply for the control system. This air is drawn from the brake reservoirs shown dotted in Fig. 80 and flows through a cutout cock, a strainer, a reducing valve (which lowers the pressure), and an equalizing reservoir (which prevents reduc-

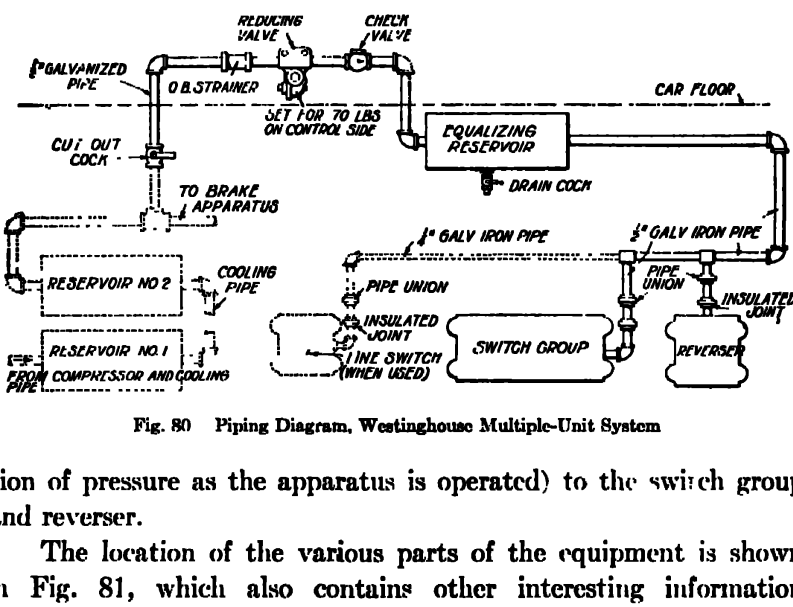


Fig. 80 Piping Diagram, Westinghouse Multiple-Unit System

tion of pressure as the apparatus is operated) to the switch group and reverser.

The location of the various parts of the equipment is shown in Fig. 81, which also contains other interesting information regarding matters already taken up in detail and others still to be considered. The illustration indicates how carefully all the space under the car floor must be utilized in order to accommodate all this apparatus.

Westinghouse Type HLD Control

Description. A widely used type of control is the Westinghouse HL equipment, the letter H signifying hand acceleration and L denoting line, not battery, control. A modification of HL

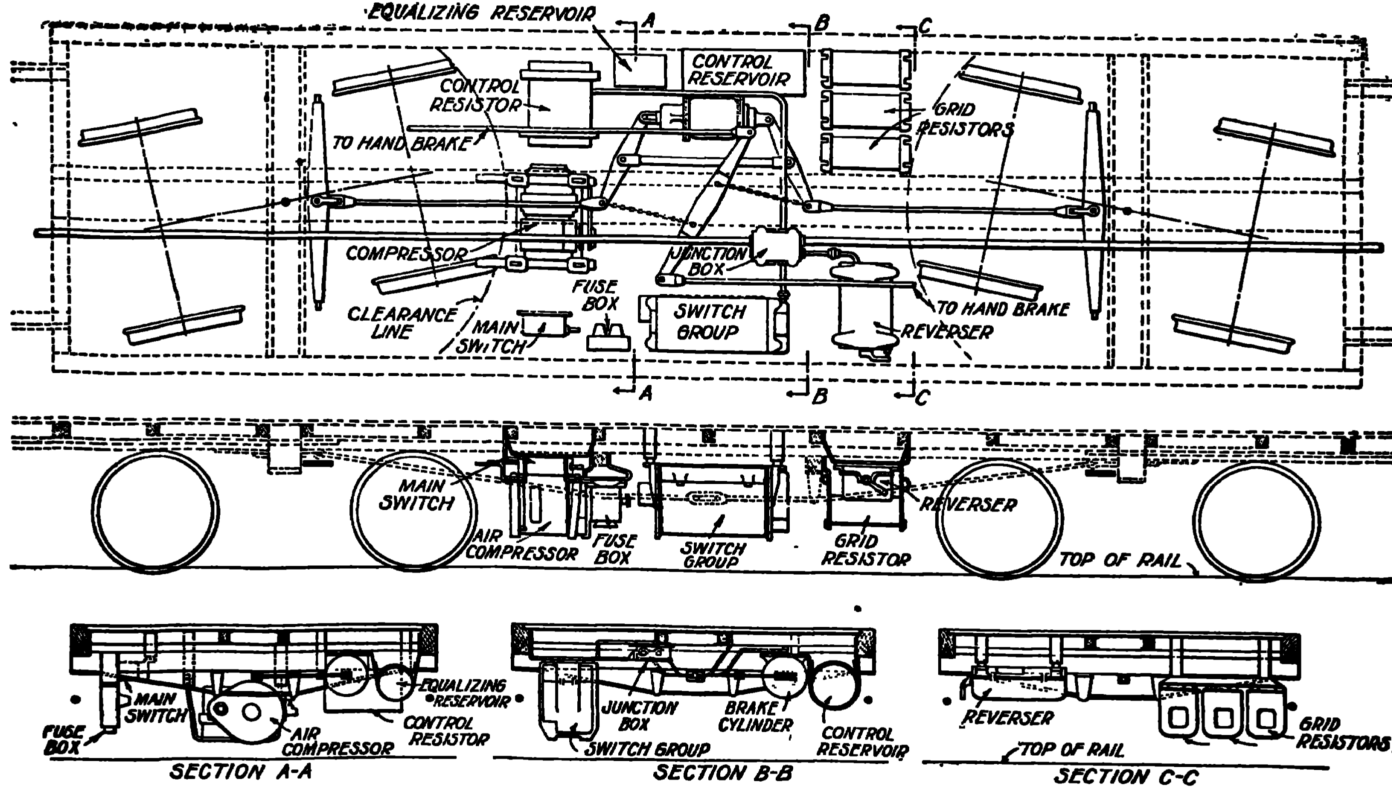


Fig 81 Diagram of Apparatus under Car. Westinghouse Multiple-Unit System

control is known as type HLD and is being employed quite extensively for light-weight low-floor cars where it is desirable to place the main circuits and circuit-breaking devices underneath

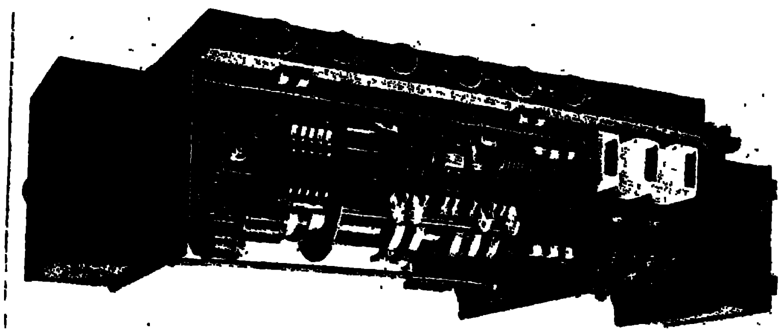


Fig. 82. Westinghouse HLD Controller Box with Covers Removed

the car. The HLD control is a combination of light weight, HL control and K control and is designed for handling four 40-hp. motors and lighter equipments. The main circuits are opened and closed by three pneumatically operated switches, while the resistance is cut in and out by a motor-operated drum, the principle being similar to that employed in the K controller. This equipment can be adapted to train operation, and automatic acceleration can be secured without serious complication. In

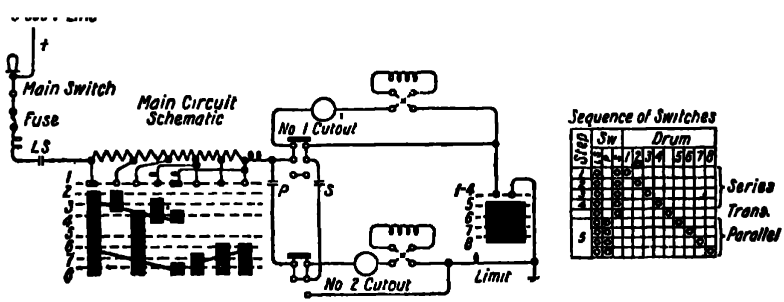


Fig. 83. Main-Circuit Diagram of HLD Control

Fig. 82 is shown the arrangement of the parts in a single enclosing case to facilitate installation and inspection. A simplified wiring diagram showing the main circuits is given in Fig. 83.

MISCELLANEOUS EQUIPMENT

Automatic Acceleration of Manual Controllers. *Automotoneer.* A large part of the difficulty in maintaining equipments results from too rapid acceleration. Various devices have been used to

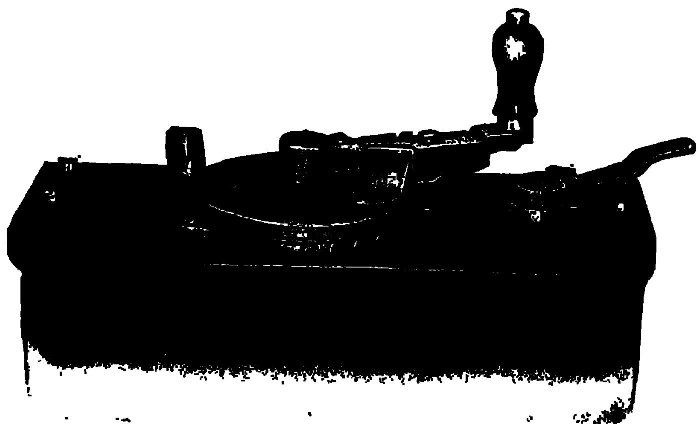


Fig. 84. Automotoneer in Place

prevent this. The multiple-unit control readily admits of automatic acceleration, but this is possible also with manual controllers. A simple mechanical device for this purpose is the automotoneer,

Fig. 85. Automotoneer Parts

Figs. 84 and 85; this is mounted on the top of the ordinary controller. It consists of two main parts, one stationary and the other rotated by the controller handle. The stationary part

contains a zigzag groove, in which plays a movable tongue, or pawl, carried by the movable part. As the handle is rotated, the pawl catches in the angles of the groove and allows the handle to be rotated one notch at a time only. In order to disengage the pawl, the handle must be moved slightly backward on each notch. This operation delays the movement of the controller drum sufficiently to prevent the motorman from drawing an excessive amount of current each time the car starts, thus saving the replacement of fuses and preventing wear and tear on the equipment and the power plant.

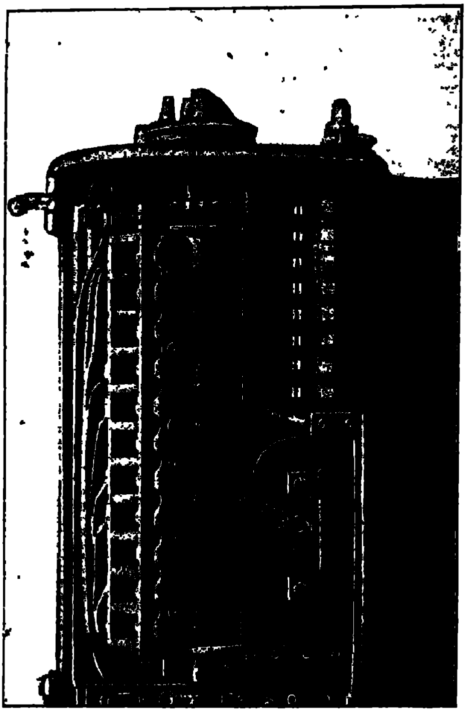


Fig. 86. Current-Limit Relay Used by Denver Railway Company

Current-Limit Relay. A simple electrical device is illustrated in Figs. 86 and 87. This is a coil and plunger mounted in the controller case. When excessive current is drawn, the plunger is attracted into the coil and pushes a bronze plug under the star wheel of the controller, where it engages a pin which stops the movement of the controller handle. When the current falls below a predetermined value, the plunger is automatically withdrawn, thus allowing farther movement of the handle until another excessive demand is made upon the circuit.

General Electric Control for 1200-Volt Equipment. Although the standard voltage in use on trolley systems has for several years been 600 volts, there has been a strong tendency lately to increase this voltage on interurban-railway systems to 1200 volts. This necessitates either the use of two 1200-volt motors or the use of two pairs of 600-volt motors, the motors of each pair being

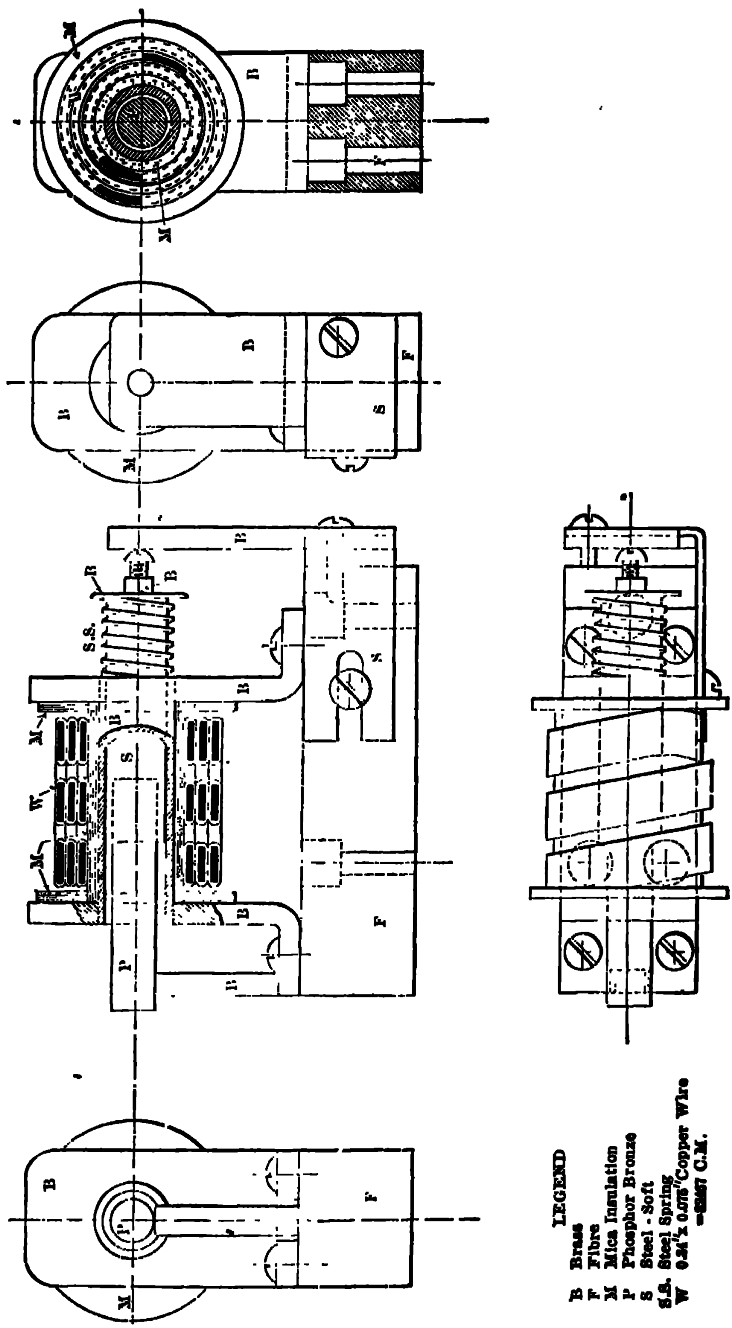


Fig. 87. Plan, Elevation, and Section of Current-Limit Relay

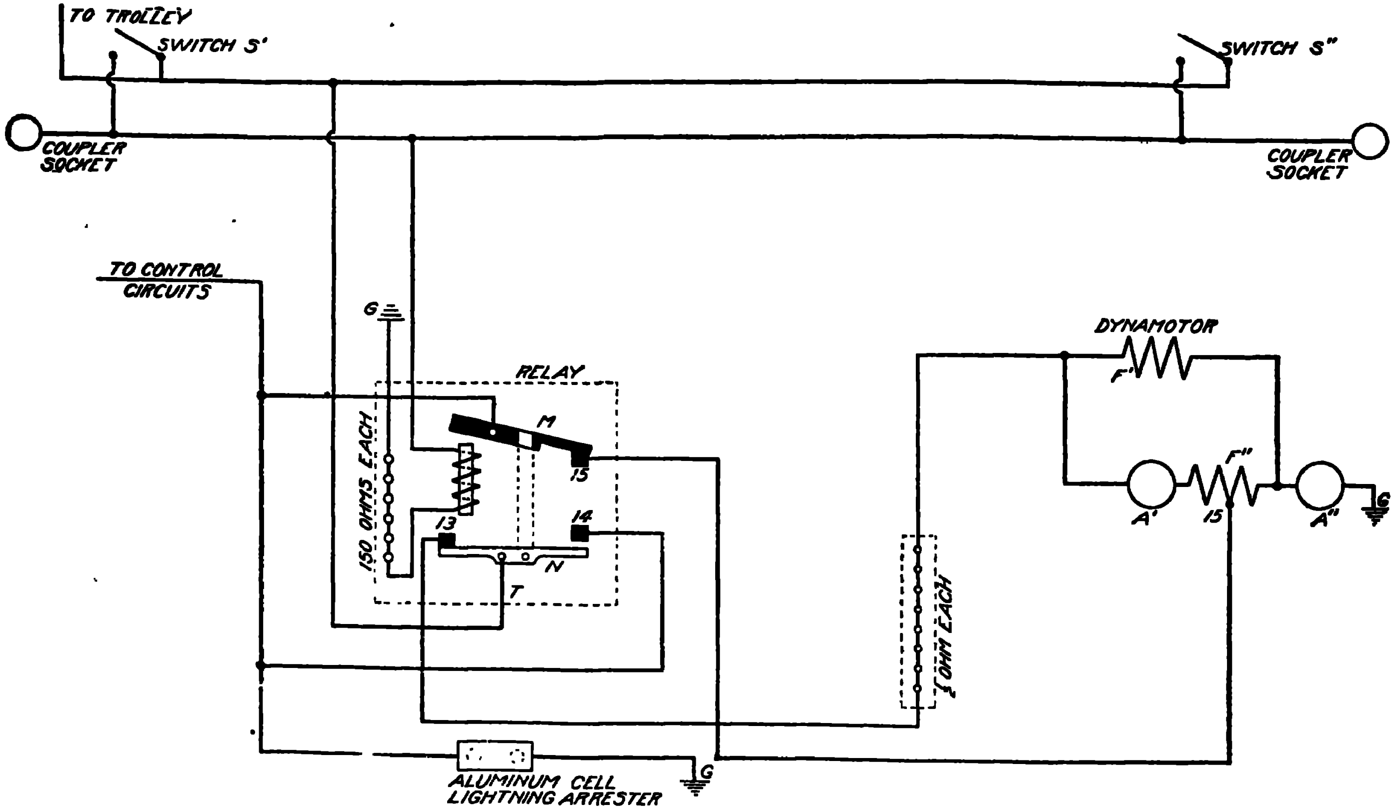


Fig. 88 Diagram of Control Apparatus of General Electric 1200-Volt Car Equipment

in series for operation on 1200 volts. As the low-voltage motors are standard and are more cheaply maintained than the others (on account of the smaller electrical strain upon the insulation), they have been largely used in the high-voltage lines.

There is an additional advantage in the use of the low-voltage motors in that, if it is desired to operate them on systems using 600 volts, they can be run at the same speed as on 1200-volt lines by simply connecting all four motors in parallel.

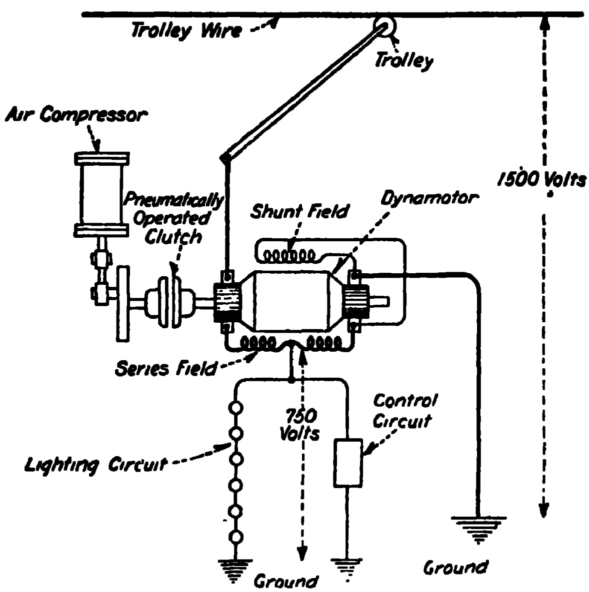


Fig. 80. Diagram of Connections for 1500-Volt Dynamotor-Compressor

In high-voltage equipments the lamps, control circuits, and in some cases the air compressors are supplied with 600-volt current. This permits the use of standard apparatus. These circuits are connected between trolley and ground through a machine known as a dynamotor, which, as its name implies, is both a generator and a motor. It is a small, d.c., compound-wound motor with two windings on the armature and two commutators, one on each end of the shaft.

The two armature windings, which are shown diagrammatically as A' and A'' in Fig. 88, are connected in series across the line. Current at one-half line voltage is taken off between the

left-hand terminal and the center (the point marked *15*) of the series field F'' and then sent through the control circuits, etc. If the equipment were designed to operate on high line voltage continuously, no additional equipment in the control circuit would be required. This apparatus, however, is designed to operate on either 1200-volt or 600-volt circuits, and as the dynamotor is not necessary at the lower voltage, some device must be used to cut it out of the circuit when it is not needed and to connect the control circuits direct to the trolley. This adjustment is accomplished by the aid of a special form of relay and a switch.

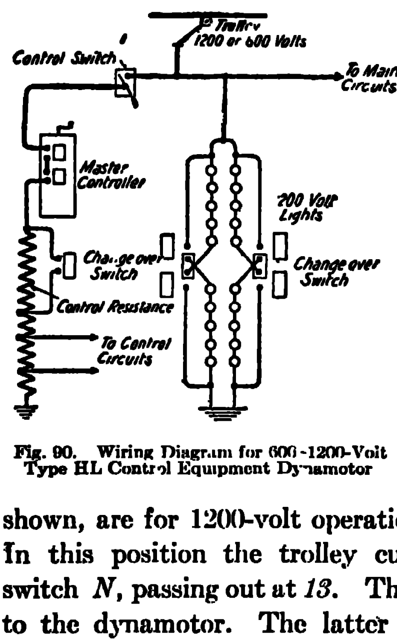


Fig. 90. Wiring Diagram for 600-1200-Volt Type HL Control Equipment Dynamotor

The relay is shown diagrammatically in Fig. 88. It consists of a coil and core with a pivoted iron armature M above. When the coil is energized, the core attracts the armature. The armature carries a switch arm, which makes and breaks contact at *15*. Below the coil is a second pivoted switch arm N, which makes and breaks contact at *13* and *14*. The lower arm is connected with the upper by the link represented by the dash line. The positions of the moving parts of the relay, as shown, are for 1200-volt operation, the solenoid circuit being open. In this position the trolley current enters at the pivot of the switch N, passing out at *13*. Thence it flows through the resistance to the dynamotor. The latter has a shunt field F' and a series field F'' and two armatures A' and A'', all connected as shown. The dynamotor then operates as a compound-wound motor.

The current for the control circuits, and any others requiring 600 volts, is taken off from the middle of the field winding and flows through contact *15*, switch arm M, and the control circuits to ground.

When it is desired to operate the control circuits directly on the line, that is, when the line voltage is 600 volts, switch S' or S'' is closed and the relay solenoid is energized. This results in

the armature *M* being attracted, and as switch *N* is connected to it, both switch arms are simultaneously operated. Contacts *15* and *13* are thus opened, cutting the dynamotor entirely out of circuit. Current now flows from the trolley through the pivot of switch arm *N*, through contact *14*, direct to the control circuits.

The connection of wire *15* at the middle of the series field winding is an important feature of the success of this scheme. When the dynamotor starts up, the current in the series winding is effective in producing a powerful torque as it strengthens the field. When current is drawn from the middle of the series winding to supply the control circuits, it flows partly through armature *A'* and partly through *A''*. These two components of the current flow in opposite directions in the series winding and thus neutralize each other. The series winding has, therefore, no effect on the operation of the machine when it is running as a generator, but is effective only when it is a motor.

Westinghouse Control for 1200-Volt and 1500-Volt Equipments. Control current is obtained in the Westinghouse high-voltage d.c. car equipment from a dynamotor-compressor, which combines the duties of the dynamotor and air compressor. The dynamotor runs continuously on either a 600-volt or a 1200-volt trolley, and the compressor is connected or disconnected by a clutch operated by the air-pressure governor. In some cases, also, the dynamotor is dispensed with and control current is obtained by tapping a section of resistance connected between the trolley and the ground. In this case the lighting and heater circuits are connected directly to the 1200-volt trolley. Simplified wiring diagrams for high-voltage car equipments using these connection are shown in Figs. 89 and 90.

BOOSTER-TYPE LIGHTING ROTARY CONVERTER, 17000 AMPERES, 25 CYCLE—LARGEST OF ITS KIND

Courtesy of Westinghouse Electric and Manufacturing Company

ELECTRIC RAILWAYS

PART II

TRACK CONSTRUCTION

General Data. A railway track consists of steel rails securely attached to crossties, which in turn are placed in a bed of broken stone, gravel, or concrete. Under the ballast or the bed of con-

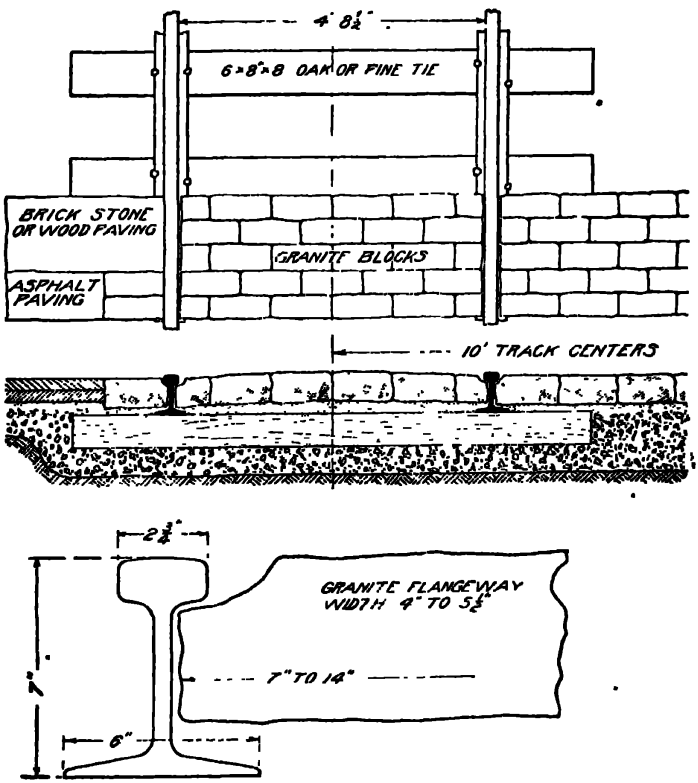


Fig. 91. Plan and Section of Typical City Track

crete is a foundation of solid earth or of large stones. A cross-section of a typical city track is shown in Fig. 91 and of an interurban track in Part III, Fig. 197.

The rail lengths are joined together by some form of joint, and where tracks cross or branch special work is put in. "Special work" is a term applied, therefore, to crossings, switches, turnouts, etc.

RAILS

Common T Rail. The T rail used by steam railroads is known as the A. S. C. E. standard T rail because it follows the standard dimensions recommended for T rails by the American Society of Civil Engineers. A standard 65-pound T rail of this kind is shown in Fig. 92. Other weights of this rail have the same relative proportions. Such a rail is used for interurban electric roads and for suburban lines in streets where there is no block paving. The rail consists of three parts: the head, the web, and the base. The

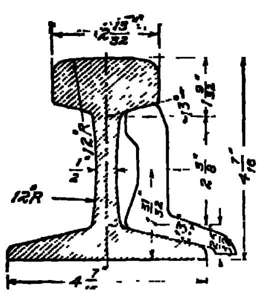


Fig. 92 Section of 65-Pound T Rail

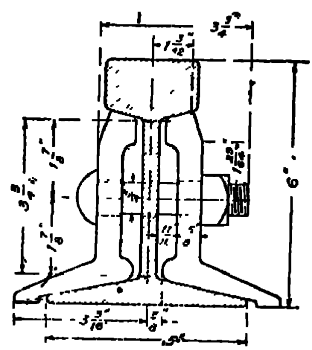


Fig. 93. Shanghai T Rail

head is designed to contain enough steel so that it will wear for a reasonable time, and the quality of steel is chosen to give the head the necessary wearing qualities. The web gives stiffness to the rail, and its thickness and depth are chosen so as to give the proper support to the head. The base, which rests on the ties, is made wide enough to distribute the pressure over as great a tie surface as possible and to give the rail the necessary stability when subjected to side pressure. The base is spiked or bolted to each tie on both sides. Long experience of steam railroads and rail manufacturers has determined the proper proportions, weights, and composition of standard T rails so as to meet the requirements of operation (wearing qualities and stiffness) with a minimum amount of steel per yard.

Shanghai T Rail. Where the T rail is to be used with paving, the popular form is the Shanghai T, Fig. 93. This rail is tall enough to permit the use of high paving blocks around it.

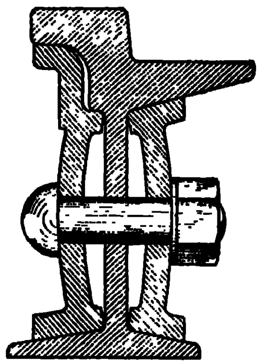


Fig. 94. Girder Rail

Girder Rail. In the early days of electric traction the most common form of rail for city use was the girder, a typical section of which is illustrated in Fig. 94. This is an outgrowth of the old tram rail used on horse railways. It has a flat projection, the tram, alongside the head, on which vehicles may be driven. The flat steel surface makes an excellent rolling surface for wagon and carriage wheels, the gage of which usually corresponds to that of standard track (4 feet $8\frac{1}{2}$ inches). Its chief advantage from the standpoint of the railway company is that there is plenty of room for dirt and snow to be pushed away by the flanges of the cars. If the company maintains the paving, it may be to its advantage to have teams use the steel track rather than the paving, although this advantage in maintenance is probably more than counter-balanced by the delay of cars through the regular use of the track by teams.

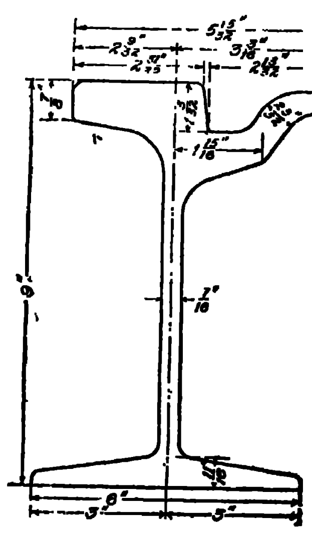


Fig. 95. Trilby or Grooved Rail

Trilby or Grooved Rail. A modification of the girder rail, known as the Trilby, and sometimes as the grooved girder, is shown in Fig. 95. It has a groove of such a shape that the flanges of the car wheels will force snow and dirt out of it instead of packing it into the bottom of the groove, as in the case with the regular European narrow-grooved rail. A narrow-grooved rail in which the grooves correspond closely to the shape of the car-wheel flanges is sure to make trouble in localities where there is snow and ice, as the grooves become packed and derail the cars. A number of varieties

of this type of rail are in use. They differ principally in the height of the lip shown at the right in the illustration. This may be higher than the head or lower, or it may be, as in the section shown, nearly on the same level.

Guard Rail. On T-rail curves it is customary to use a guard rail which bears against the inside of the wheel flange and assists in holding the wheel to the rail. The guard rail is of a special form (see the mate, Fig. 106). It is bolted to the inside of the rail web. Guard rails may be improvised out of old standard rails bolted to the main rail with spacing blocks between, but the regular sections are to be preferred.

Composition of Rails. As the qualities of steel are very greatly affected by its chemical composition, specifications drawn by railway companies are very rigid in this matter. For rails of average hardness and ductility the following specifications may be taken as typical:

Constituent	Percentage Present
Carbon	0.75 to 0.85, average 0.80
Sulphur, not to exceed	0.04
Phosphorus, not to exceed	0.03
Silicon, not to exceed	0.20
Manganese	0.80 to 0.90

Open-Hearth Steel. Open-hearth steel is being used to an increasing extent with satisfactory results. The standard composition for this steel does not differ substantially from the foregoing specifications except that the percentage of carbon is less—0.60 to 0.75 per cent.

Manganese Steel. Manganese steel is one of the latest developments in steel rails. Manganese steel has been cast for some time, but only within the past few years has it been possible to obtain it in the form of rolled rails. The ability of this material to withstand wear is very great—many times that of ordinary steel. The composition is about as follows:

Constituent	Percentage Present
Carbon	0.90 to 1.20
Phosphorus	not over 0.10
Silicon	not over 0.50
MANGANESE	9.50 to 16.00
Sulphur	not over 0.06

RAIL JOINTS

Ordinary Bolted Joint. The ideal track would have continuous rails, but as rails are made in lengths of either 30 to 33 feet or about 60 feet, this ideal condition can be realized only by using joints which give the same effect as a continuous rail. In ordinary track the joints are the weakest part, and rails wear out from the hammering effect at loose joints long before they would if there were no joints. The ordinary joint is made by bolting a pair of angle bars or fish plates to the sides of the rail. Sections through such joints are shown in Figs. 92 and 93. The edges of these bars are made accurately to such an angle that they will wedge in

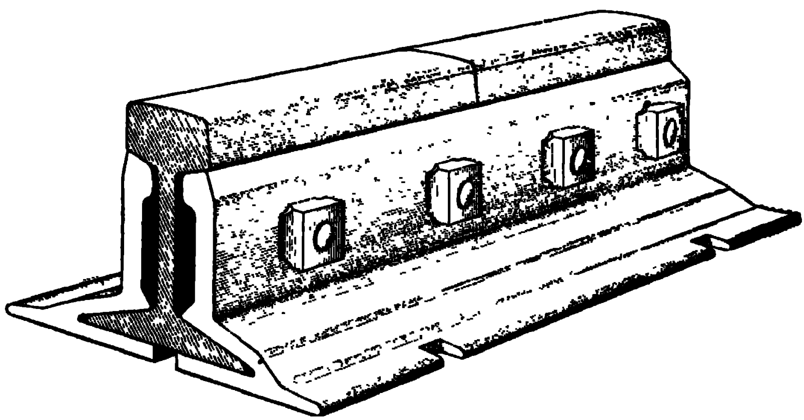


Fig. 96. Continuous Rail Joint

between the head and base of the rail as the bolts are tightened; hence the name "angle bars." This is the form of joint generally used on steam railroads and on electric roads in exposed track or in track where the joints are easily accessible, as in dirt streets. In paved streets the undesirability of tearing up the pavement frequently to tighten the bolts on such joints has led to the invention of several other types, which will be described later. Nevertheless, very good results have been obtained with bolted joints laid in paved streets where care has been given to details in laying the track and where the joints have been tightened several times before the paving is finally laid around them.

Improved Joints. As angle bars do not give altogether satisfactory service, particularly in paved streets, as explained above,

numerous improved joints have been brought out. The purpose of these is to secure permanence without excessive stiffness; that is, the joint is designed to be about as flexible as the continuous part of the rail. Cross-sections of several of these are shown in Figs. 96, 97, and 98. Each of these supports the base of the rails and also produces a wedging effect between the base and the head of the rail. The *continuous* joint, Fig. 96, grips the base above and below. The *Weber* joint, Fig. 97, has a flat base, which is spiked to the tie, in addition to the angle plates. The base plate has a vertical plate projecting from it, and this is separated from one of the angle plates by a wooden block or filler for the purpose of utilizing the elasticity of the wood in giving a tight but flexible joint. The *Wolhaupter* joint, Fig. 98, has a corrugated base plate, and the angle bars are so formed as to grip this plate and the base of the rail. The ends of the rails are thus bound together all around.

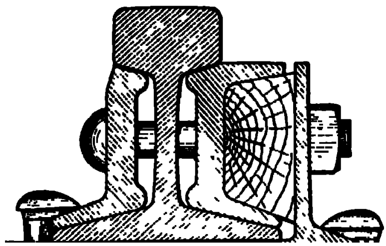


Fig. 97. Weber Joint

Welded Joints. Several forms of welded joints are in use. All these welded joints fasten the ends of the rails together so that the rail is practically continuous—just as if there were no joints—so far as the running surface of the rail is concerned. It was thought at one time that a continuous rail would be an impossibility because of the contraction and expansion of the rail under heat and cold, which, it was supposed, would tend to pull the rails apart in cold weather and cause them to bend and buckle out of line in hot weather. Experience has conclusively shown, however, that contraction and expansion are not to be feared when the track is covered with paving material or dirt. The paving tends to hold the track in line and to protect it from extremes of heat and cold. The reason

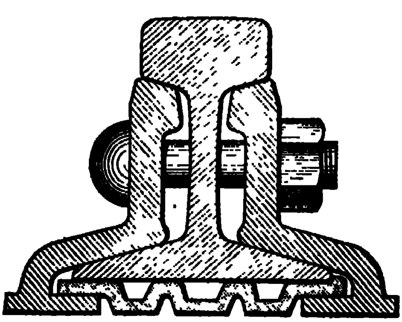


Fig. 98. Wolhaupter Joint

that contraction and expansion do not work havoc on track with welded joints is probably that the rails have enough elasticity to provide for contraction and expansion without breaking. It is found that the best results are secured by welding rail joints during cool weather, so that the effect of contraction in the coldest weather will be minimum. In this case, of course, there will be considerable expansion of the track in the hottest weather, but this does not cause serious bending of the rails; whereas, occasionally, if the track is welded in very hot weather, the contraction in winter will cause the joint to break.

Fig 99 Apparatus Set for Cast-Welded Joint

Cast-Welded Joints. The process of cast-welding joints consists in pouring very hot cast iron into a mold placed around the ends of the rails. These molds are of iron; and to prevent their sticking to the joint when it is cast, they are painted inside with a mixture of linseed oil and graphite. Iron is usually poured so hot that, before it cools, the base of the rail in the center of the molten joint becomes partially melted, thus causing a true union of the steel rail and cast-iron joint. This makes the joint mechanically solid and a good electrical conductor. To supply melted cast iron during the process of cast-welding joints on the street, a

small portable cupola on wheels is employed. In Fig. 99 is given an idea of the process of making cast-welded joints.

Electric-Welded Joints. An electric-welded joint is made by welding steel bars to the rail ends. A steel bar like that

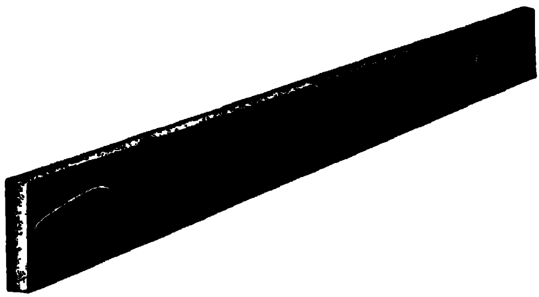


Fig. 100. Steel Bar for Electric-Welded Joint

shown in Fig. 100 is placed on each side of the joint, and current of very large volume is passed through from one block to the other This current is so large that the electrical resistance between the rail and steel block causes that point to become molten. Current is then shut off, and the joint allowed to cool. There is in this case a true weld between the steel blocks and the rails and joint. The appearance of such a joint is shown in Fig. 101.

An electric-welding outfit being expensive to maintain and operate, this process is used only where a large amount of weld-

Fig. 101. Electric-Welded Joint

ing can be done at once. The direct current is taken from the trolley wire at 500 volts and passed through a rotary converter, which converts it into an alternating current. A transformer

reduces the voltage and gives a current of great quantity at low voltage, the latter current being passed through the blocks and rails in the welding process. A massive pair of clamps is used to force the blocks against the rails with great pressure and to conduct the current to and from the joint while it is being welded. These clamps are water cooled by having water circulated through them so that they will not become overheated at the point of contact with the steel blocks.

Thermit Welding. Dr. Hans Goldschmidt has invented a mixture which he calls thermit and which has been found useful in making rail welds. Thermit is a mixture of powdered aluminum and iron oxide, and these have a strong tendency to combine after they have been ignited, producing by this combination intense heat accompanied by a reduction of the iron in pure form. In making a joint an iron mold is placed about the joint somewhat as in the cast-welding process. The space inside the mold is, however, very much smaller. A charge of the thermit, sufficient for a joint, is placed in a funnel-shaped sheet-iron crucible, which is lined with refractory material. The bottom of this can be opened to allow the molten iron to flow into the mold. The charge is ignited by a small charge of fulminate, and almost instantaneously the metal is ready for pouring. The combination of the materials is very vigorous, so that the crucible must be covered to prevent them from flying out. This process has an advantage in that, as it does not require elaborate apparatus and a large crew of men to operate it, a few joints can be made to advantage. The iron which flows into the mold is at such a high temperature that it melts the steel of the rail with which it comes in contact and produces an actual weld. For further details, see the text on "Welding."

TRACK SUPPORT

Ties. The greater portion of track is laid on wooden ties. These ties, in the most substantial wooden-tie construction, are 6 inches by 8 inches in section and 8 feet long. They are spaced 2 feet between centers. Sometimes smaller ties, spaced farther apart, are used in cheaper forms of construction; but the foregoing figures are those of the best construction known in American railway practice. In paved streets ties are usually employed,

although sometimes what is known as concrete-stringer construction is used instead of ties to support the rails. A strip of concrete about 12 inches deep is laid under each rail, and the rails are held to gage by ties or tie rods placed at frequent intervals. Sometimes the concrete is made a continuous bed under the entire track. In most large cities the concrete foundation is used under all paving; and consequently, when concrete is used instead of ties to support the rails, this concrete is simply a continuation of the

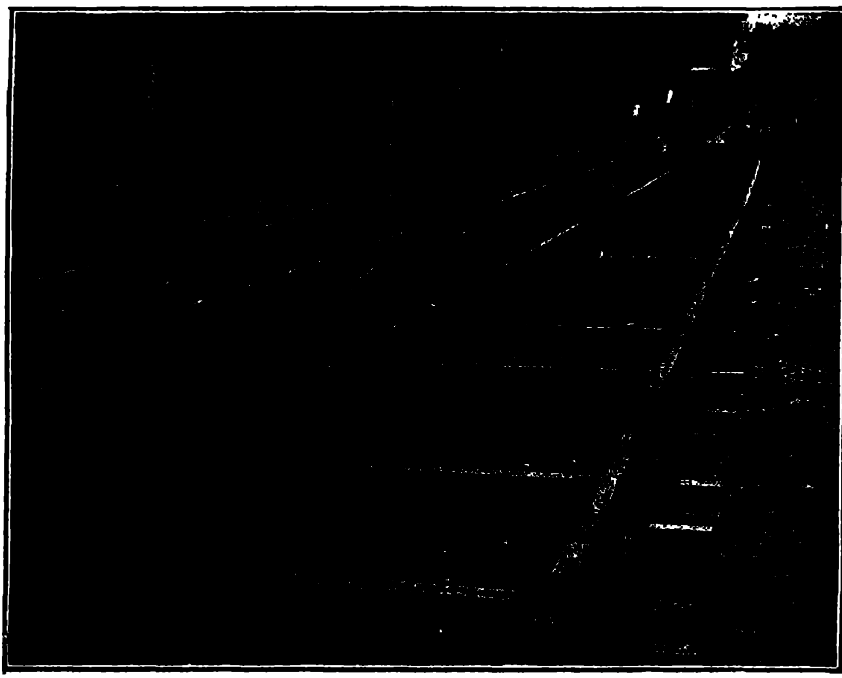


Fig. 102. Steel Tie and Tie-Rod Connection

paving foundation. Where ties are used, they are laid sometimes in gravel, crushed stone, or sand, although frequently in the largest cities they are embedded in concrete. Sometimes this concrete is extended under the ties, and sometimes it is simply put around the ties.

Preservation of Wooden Ties. The increasing cost of wooden ties, the difficulty of obtaining good ones, and the comparatively short life of these ties have resulted in the development of substitutes. Wooden ties, however, possess many advantages. They

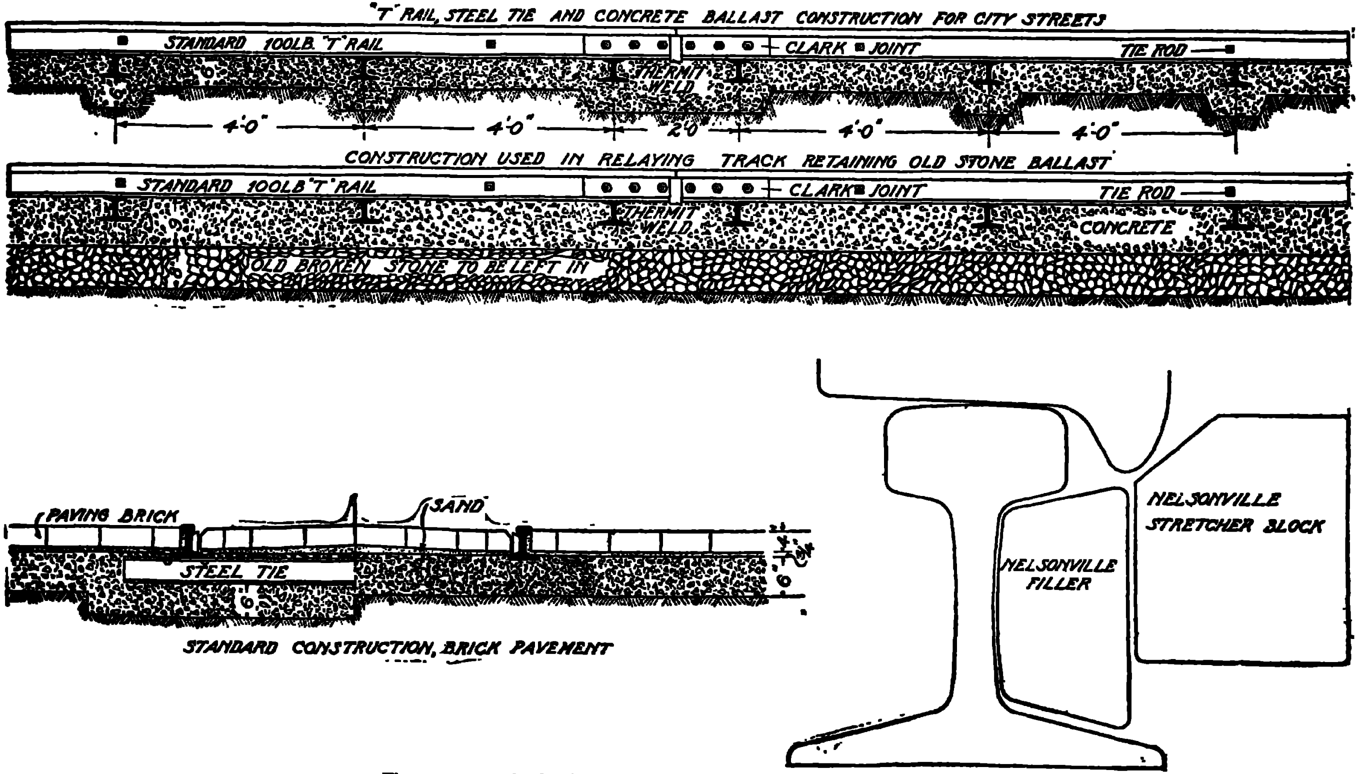


Fig. 103. Longitudinal and Transverse Section of Steel Tie Track Bed

are cheap; they produce a resilient easy-riding track; rails are easily and cheaply attached to them, etc. Efforts are, therefore, being made to extend the life of ties by means of preservatives, of which the most commonly used are zinc chloride, creosote, and crude oil. In order to properly apply the preservative it is necessary to first remove the sap and air from the wood, which is accomplished by means of heat. On cooling, the wood tends to absorb the preservative. This matter is considered so important by the government that the Forest Service has established a Department of Wood Preservation. Anyone who is interested in a practical way in preserving the life of ties, poles, posts, etc., can obtain information and assistance from the department. The steam railroads are adopting plans for tie preservation on a large scale and will thus at least double the life of their ties.

Substitutes for Wooden Ties. While efforts are being made to extend the life of wooden ties, substitutes are also coming rapidly into use. In cities the stringer construction, previously mentioned, is popular. Steel ties are also being employed on a large scale. These are crossties laid like the wooden ones, except that in city work they are bedded in concrete. The construction is shown clearly in Figs. 102 and 103. A feature shown in Fig. 102 which has not been mentioned before is the use of tie rods which maintain the rails at the proper distance apart. These are flat straps with threaded bolts on the ends; the latter pass through holes in the rail web.

Ballast. A ballast of gravel, broken stone, cinders, or other material which is self-draining and which will pack to form a solid bed under the ties should be used to get the best results under all forms of construction, whether in paved streets or on a private right of way, as on an interurban road. Of course, if concrete is placed under the ties, the gravel or rock ballast is not necessary. If ties are placed directly in soft earth, which forms mud when wet, they will work up and down under the weight of passing trains, and an insecure foundation for the track will be the result. In interurban work the ballast is brought up nearly to the top of the ties. This insures a quiet track, that is, there is much less vibration than if the track were insufficiently ballasted.

SPECIAL WORK

Right-Hand Crossover. The special pieces of track construction necessary in cities form a most important feature, as they must in many cases be designed for their particular locations. There are, however, standard pieces which have regular names, and the student should be familiar with the most important of them. In the crossover, Fig. 104, the dash lines show the positions of the rails of the double track, and the solid lines the special work. As indicated, there is a switch at each end of the crossover by means of which a car can be deflected from the straight track. Opposite the switch is the mate; this is a junction which allows the wheel on that rail to follow the direction determined by the position of the switch. The appearance of the

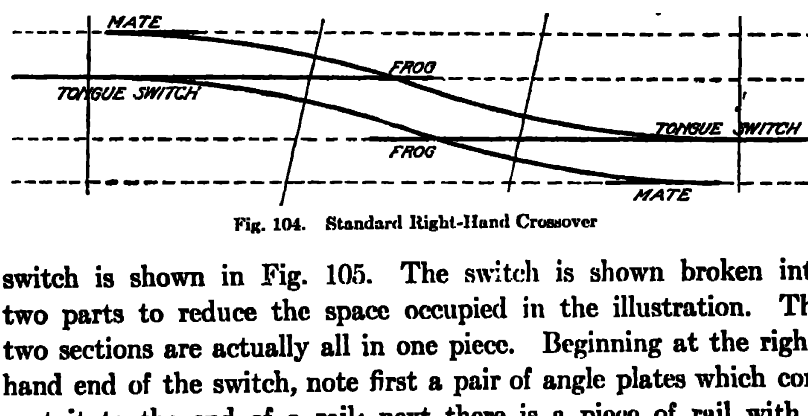


Fig. 104. Standard Right-Hand Crossover

switch is shown in Fig. 105. The switch is shown broken into two parts to reduce the space occupied in the illustration. The two sections are actually all in one piece. Beginning at the right-hand end of the switch, note first a pair of angle plates which connect it to the end of a rail; next there is a piece of rail with a guard rail firmly attached; this leads up to a casting firmly bolted to the rail and forming between it and the rail head a shallow flat-bottomed space in which plays a forged-steel movable tongue, hinged at the left; at the left end the casting widens out and the crossover rail is attached to it by means of angle plates. The position of the tongue determines whether the car wheel shall follow the main or the crossover rail.

Opposite the switch is the mate, Fig. 106. This is simply a Y joint of the main and the crossover rails with a space between the heads to allow the car wheel to follow the main rail if it is not to be deflected to the crossover rail. A short guard rail assists in guiding the wheel over the crossover rail.

Fig. 105 Typical Steel Track Switch Form in Two Parts

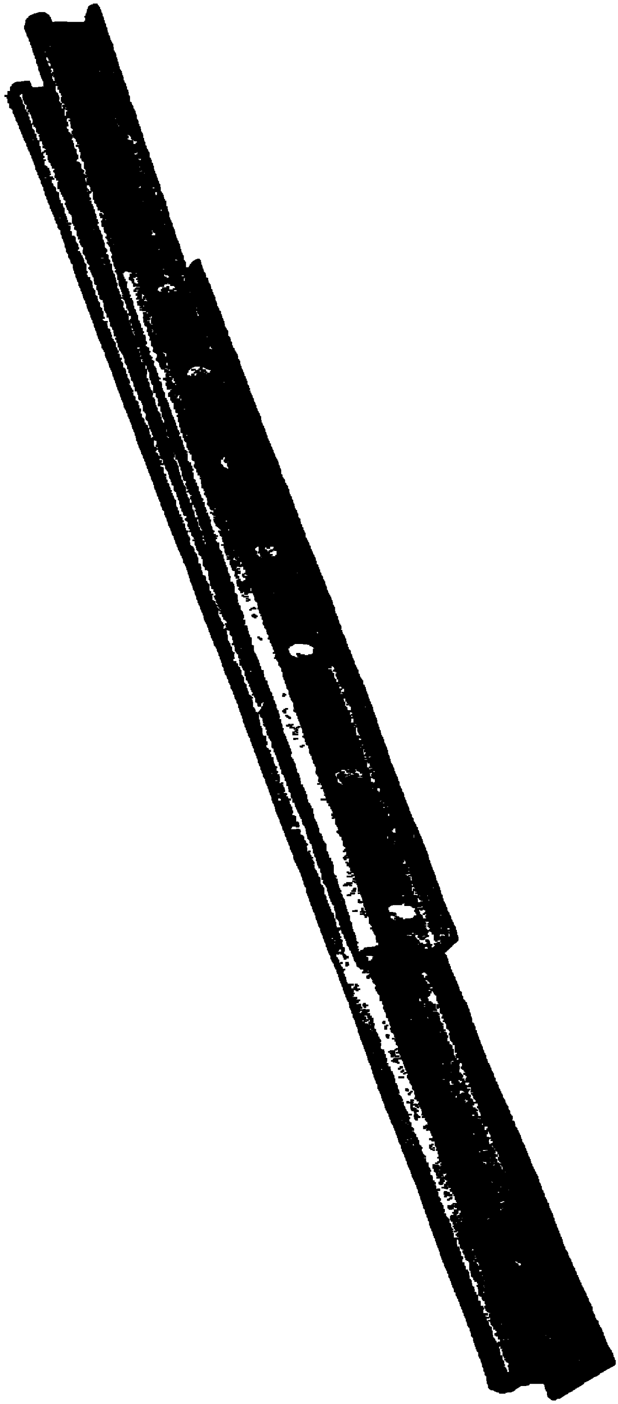


Fig. 106. Mate Form of Typical Steel Track Switch

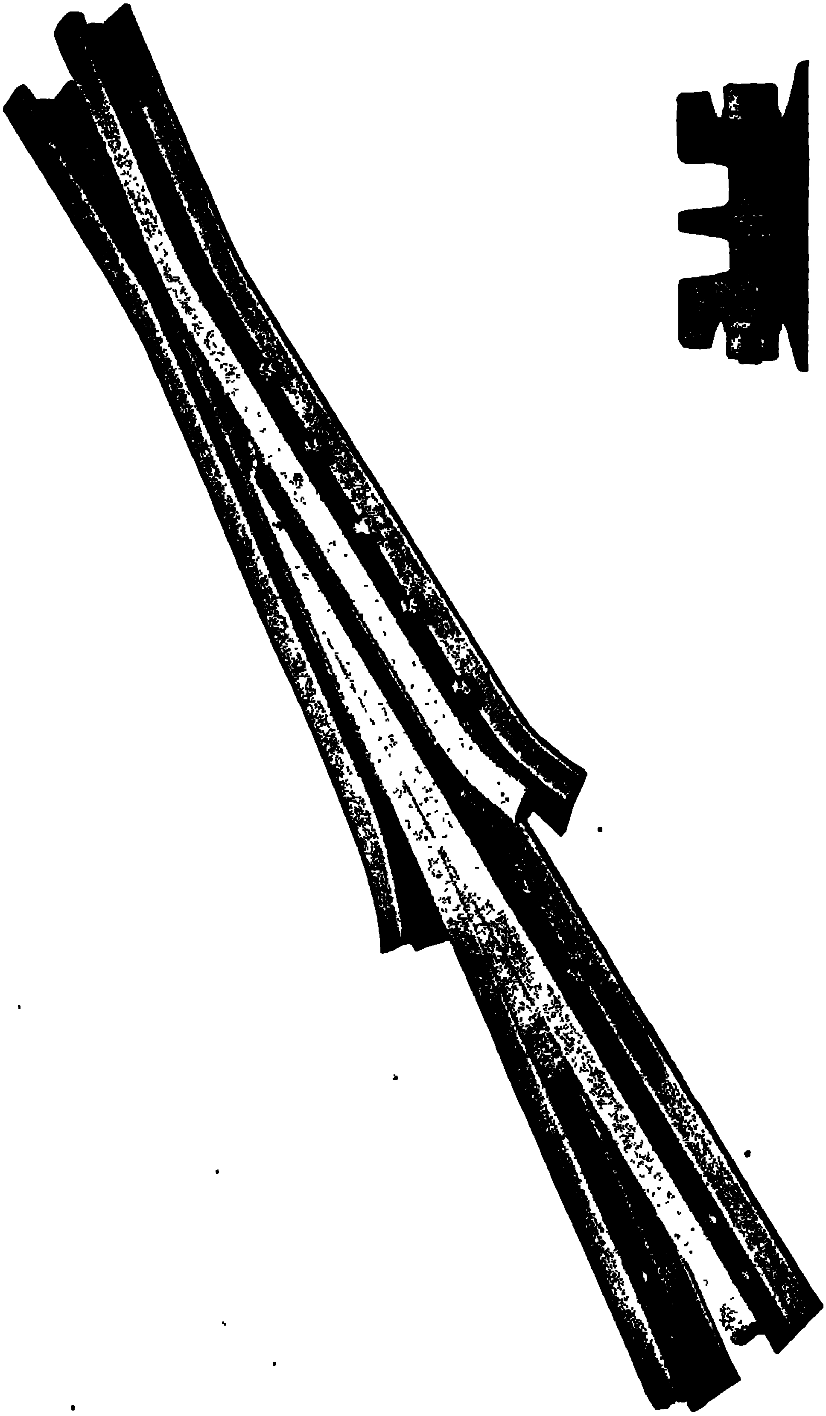


Fig. 107. View of Frog Construction in Projection and Section

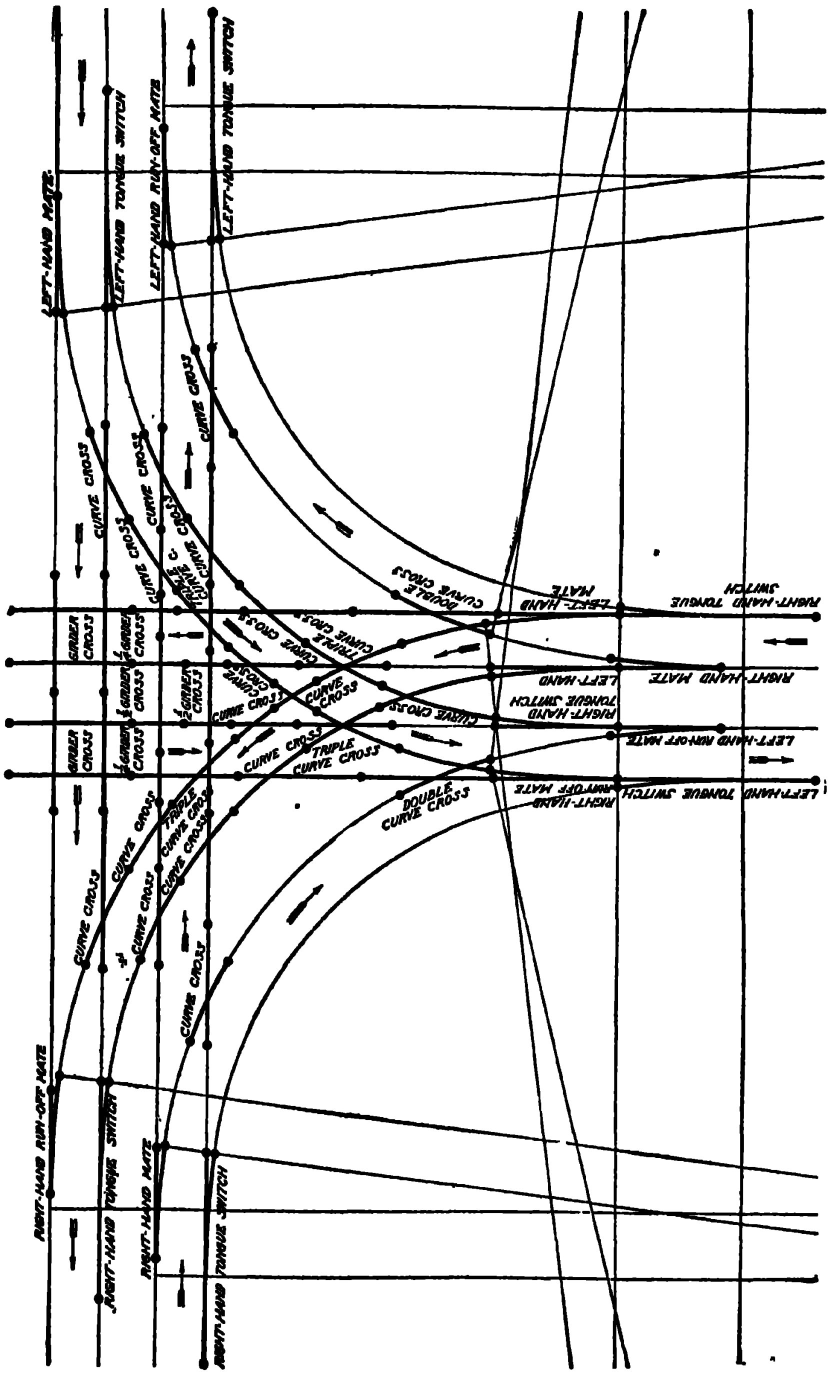


Fig. 108. Double-Track Crossover with Connecting Curves

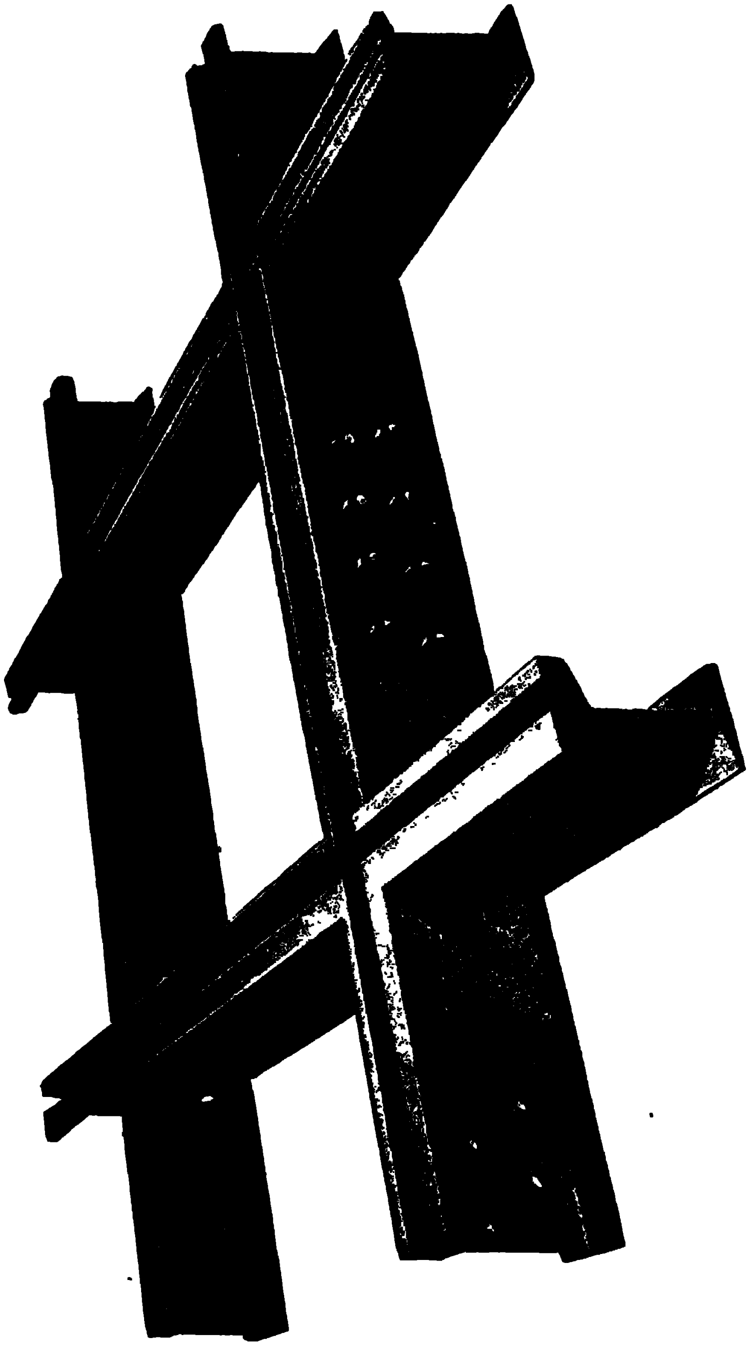


Fig. 109. Grooved-Rail Right-Angled Cross

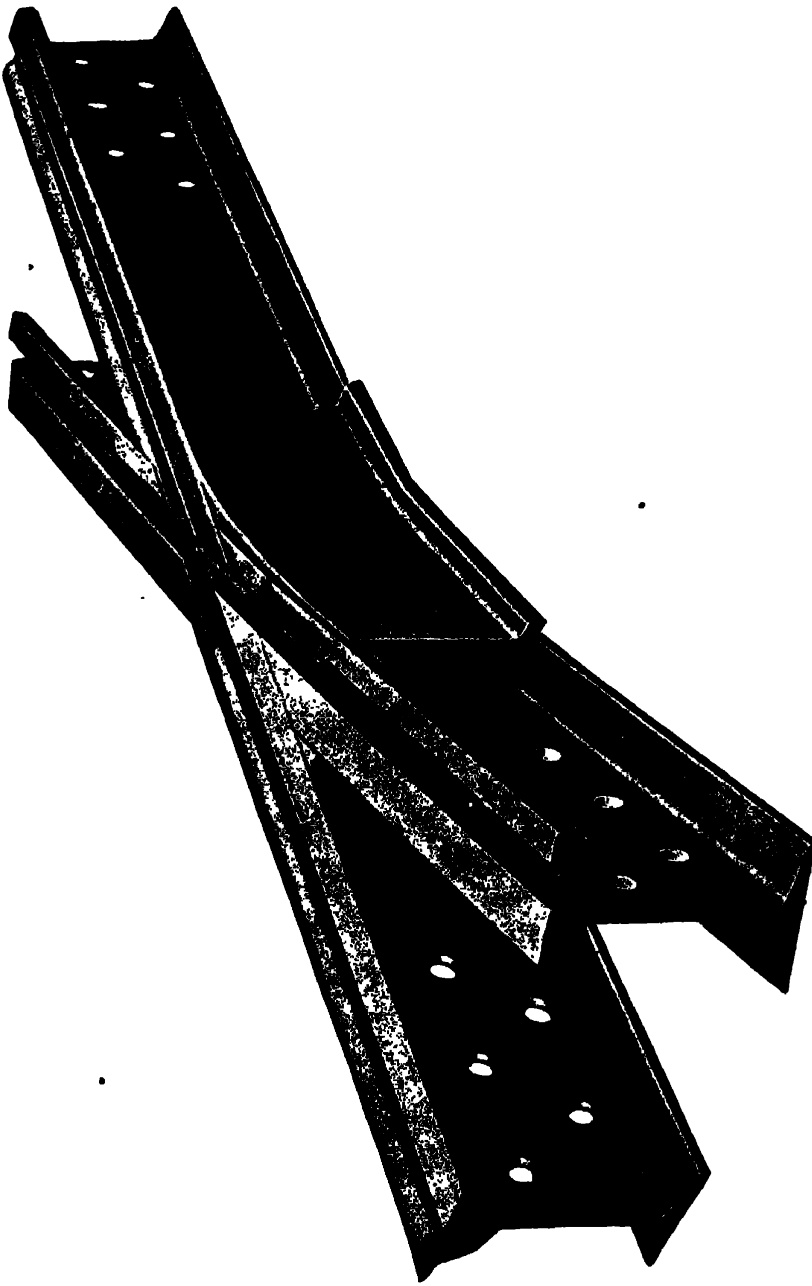


Fig. 110. Grooved-Rail Curve Cross

Where the rails cross at an angle, a frog is located. The construction of such a frog is shown in Fig. 107; it is built up of pieces of standard rail with filler blocks between, as shown in the cross-section.

Double-Track Crossover. An excellent idea of a complicated piece of work can be obtained from Fig. 108. Here two double tracks cross, and they are connected with each other by two sets of curves. The switches and mates used here are similar to those shown previously, and in addition there are right-angle and curve crosses. The light lines show the plain rail, and the heavy lines the special pieces; and the ends of each special piece are marked by black circles. The construction of these crosses is shown in Figs. 109 and 110, where the rails are held together by cast-steel pieces cast in position. The castings on the two sides are held together by the metal which has flowed through holes in the rail webs.

SPECIAL TRACK CONSTRUCTION

Underground Conduit System. *Description.* The underground conduit system, in which the conductors conveying the current to

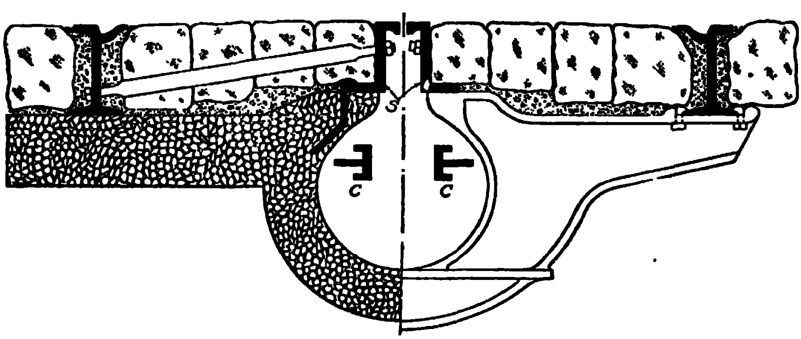


Fig. 111. Conduit for Underground Trolley System

the cars are located in a conduit under the tracks, is in use in two cities of the United States: New York City and Washington, D. C. The cost of this system and the danger of interruption of the service where the drainage is not excellent have prevented its more extensive adoption. The New York type of conduit, which is a good example of this construction, is shown in cross-section in Fig. 111. The conductors consist of T bars *CC* of steel, sup-

ported from porcelain cup insulators located 15 feet apart in the conduit. At each insulator a handhole is provided, Fig. 112, to furnish access to the insulator from the street surface. Manholes are provided at intervals of about 150 feet so that the dirt which collects in the conduit can be scraped into them and removed at intervals. The manholes also serve as points of drainage connecting with the sewer system.

Current for operating the motor is conducted to the car through a pair of contact shoes commonly called a plow, which has the two shoes insulated from each other and from the frame of the plow. These shoes are provided with flat springs that hold them against the conducting bars in the conduit. The shank of the plow is thin enough ($\frac{9}{16}$ inch) to enter the slot of the conduit. The conductors pass up through the middle. These plows can, of course, be removed only when the car is over an open pit.

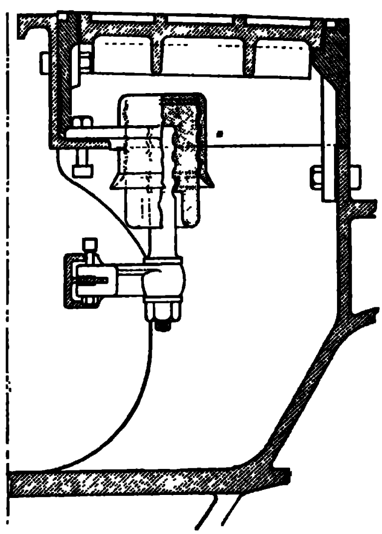


Fig. 112. Section of Underground Conduit Showing Handhole

Cost. A conduit system of this kind is very expensive to build for several reasons, three of which are as follows:

1. A very deep excavation must be made in the street to accommodate the conduit.

2. The track rails, slot rails, and sheet-steel conduit lining are all held in alignment by means of cast-iron yokes placed 5 feet apart.

3. The entire space around and underneath these yokes is filled with concrete in order to give rigidity and permanence to the track bed.

These three expensive items, therefore, cannot be avoided in the construction of a conduit road. The deep excavation may further call for the changing of other underground pipes or conduits in the street. The necessary precautions against leakage of current is also a serious expense.

CAR EQUIPMENT AND MAINTENANCE

MISCELLANEOUS CAR EQUIPMENT

TROLLEY

General Description. Current is taken from the trolley wire through a brass wheel carried in a trolley harp mounted on the

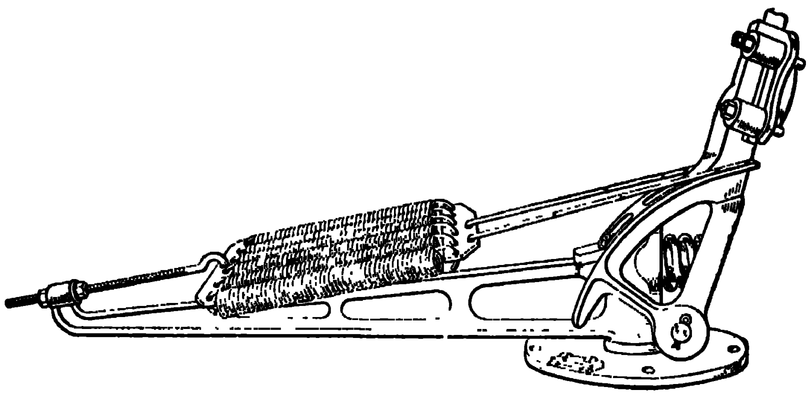


Fig. 113. Type of Trolley Base

end of a light tubular steel pole. The pole is attached at its lower end to the trolley base, which is a spring hinge pivoted on a base plate.

Base. Typical trolley bases are shown in Figs. 113, 114, 115, and 116. While these bases differ in detail, they all operate

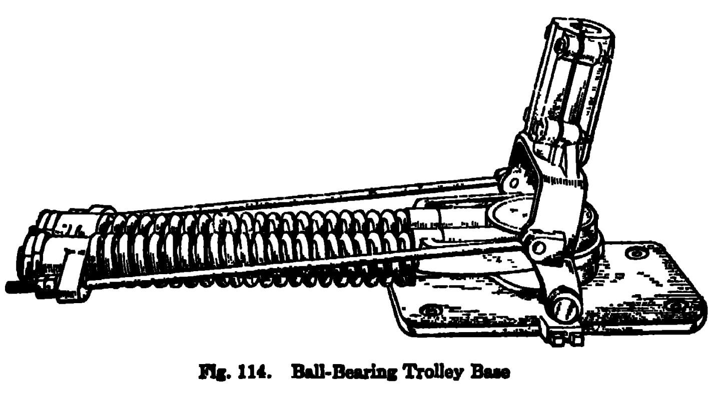


Fig. 114. Ball-Bearing Trolley Base

upon the principle of producing a uniform pressure of the wheel upon the trolley wire, regardless of the position of the pole. In

Fig. 113, which was one of the earlier types, the following essential parts can be easily seen: the stand, or foot, which is screwed to the platform or the roof of the car and is provided with a terminal binding clamp through which the current is carried to the pole and wheel; an arm, or swivel, one end of which fits over a swivel pin forming part of the stand; a socket, which is hinged at the lower

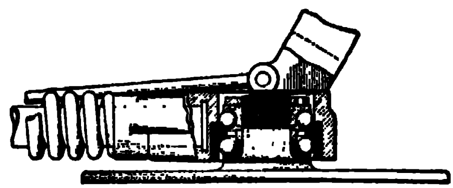


Fig. 115. Ball Bearings of Fig. 114 in Detail

end to the swivel arm and also carries a pair of cams to which the tension springs are attached; and a set of heavy steel springs with adjusting device and also a buffer spring to absorb the shock in case the trolley pole leaves the wire. The general features of this construction have been followed to a certain extent in more recent designs, and in the later types ball bearings are used instead of a swivel pin in order to permit the pole to turn more easily when rounding curves. In the later types, also, the springs are used under compression instead of under tension as in Fig. 113. In Fig. 116 is shown a base designed for high-speed interurban service; this base complete weighs 120 pounds. The bearing consists of

Fig. 116. Trolley Base for High-Speed Interurban Service

steel rollers carried in a waterproof bearing cup, sufficiently protected to operate almost indefinitely without lubrication. Four heavy tension springs are used with adjustments to allow for

setting to give a pressure of from 20 to 45 pounds upward against the trolley wire. This base will accommodate a $1\frac{1}{4}$-inch pole 14 feet in length.

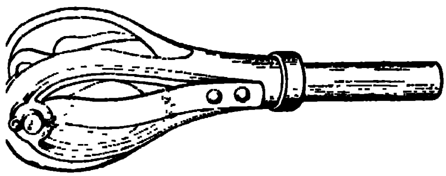


Fig. 117. Trolley Harp for Holding Pulley

Pole. Trolley poles are made of light high-grade steel tubing about $\frac{1}{8}$-inch in thickness and of a length determined by the height of the trolley wire above the car roof. The angular elevation of the trolley pole may be approximately 30 degrees. This will require poles between 12 and 18 feet in length. The steel of the poles is reasonably soft so that in general they will bend rather than break under ordinary shocks. The tubes are tapered from a point several feet from the upper end, and their outside diameter at the butt ranges from $1\frac{5}{8}$ to 2 inches. The standard outside diameter at the upper end is 1 inch, the inside being reamed to fit the standard harp shank. At the butt end the poles are reinforced by a length of tube inside, the length and strength of this tube being determined by the service to which the poles will be subjected.

Harp. The trolley harp is the device which is mounted on the upper end of the pole to carry the trolley wheel. A typical harp is

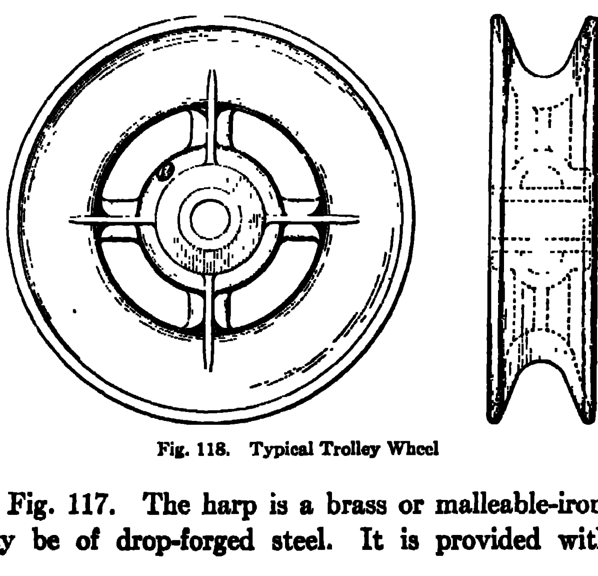


Fig. 118. Typical Trolley Wheel

shown in Fig. 117. The harp is a brass or malleable-iron casting, or it may be of drop-forged steel. It is provided with a cold

rolled-steel shank, finished carefully to standard size, which slips into the reamed hole in the upper end of the trolley pole, where it is riveted into place. At the upper part of the harp is an axle pin upon which revolves the trolley wheel. Contact springs are also provided for conducting the current from the wheel to the pole.

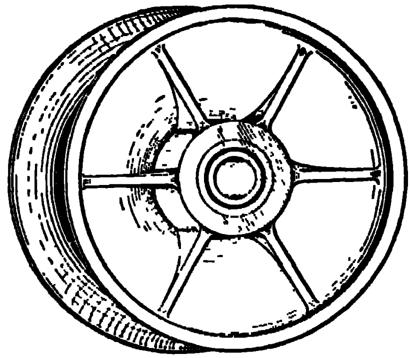


Fig. 119 Perspective View of Good Type of Trolley Wheel

Wheel. The trolley wheel is cast from brass of special composition satisfactory as to toughness and wearing qualities. The wheels are grooved as shown in Fig. 118, the grooves being of such form as to prevent the wheel from leaving the wire and at the same time to give sufficient clearance so that the wheel will not bind when the car is rounding curves. The wheels are provided with graphite bushings so that they will be self-lubricating, and in some cases oil reservoirs are cast in the hubs to furnish additional lubrication. The diameter of the wheels is determined by the speed at which they are to be operated, larger wheels being used for higher speeds. The diameter is from 4 to 5 inches for low-speed wheels, and it may be 6 inches or over for use on high-speed interurban cars. Fig. 119 shows in perspective the usual form of wheel used in cars of moderate size. A wheel used in cutting sleet from the trolley wire is illustrated in Fig. 120.

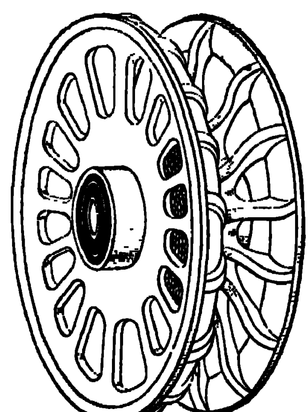


Fig. 120. Special Form of Trolley Wheel for Cutting Sleet

Catcher. The standard forms of trolley catcher are more or less like that shown in Fig. 121. The trolley rope is wound about a drum or reel mounted in an iron box on the back of the car. This drum is rotated by a spring of moderate strength, which keeps the slack rope wound up, but does not tend to pull the wheel

off the wire. On the drum is a pair of pawls, which are normally held close to it by springs. If, however, the rope is jerked suddenly, as it is when the trolley wheel slips off the wire, the pawls are thrown outward by centrifugal force and catch in lugs which are cast in the back of the case.

Retriever. A retriever is a device which not only catches the trolley rope but winds it up until the trolley wheel is below its normal position and, therefore, entirely clear of span wires and other obstructions. The usual form of retriever contains two springs, the *tension spring* for taking up the slack in the wire and the *retrieving spring*, much stronger than the other, for drawing the pole down Normally the tension spring only is in operation.

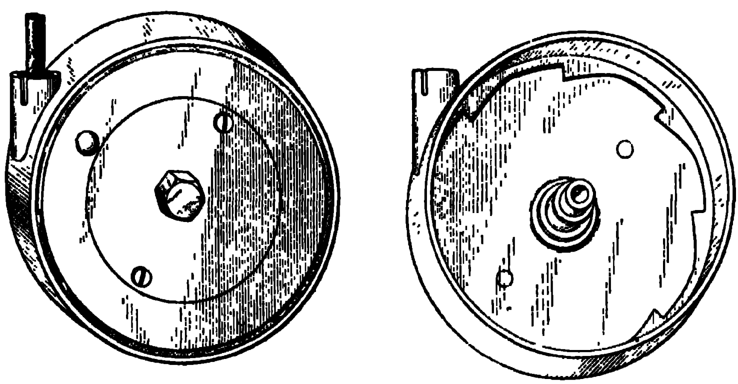


Fig. 121. Form of Trolley Catcher with Drum and Reel

When the trolley rope is jerked, a centrifugal force is applied to a weight or governor which connects the reel with the retrieving spring and releases the latter. When the trolley wheel is replaced on the wire, the conductor draws out the rope, winds the retrieving spring, and latches it in its wound-up position ready for use again. As compared with the simple catcher, the retriever costs much more, but the expense is probably justified in high-speed work.

Pantograph Trolleys. On some electric railways operating at high speeds pantograph collectors are used to avoid the possibility of the trolley leaving the wire and to collect heavier currents than are ordinarily commutated by wheel trolleys. Both roller and slider pantographs are used, the contact element being carried at

the top of a tubular steel-pipe construction which is held against the trolley wire by heavy springs. In the case of slider trolleys

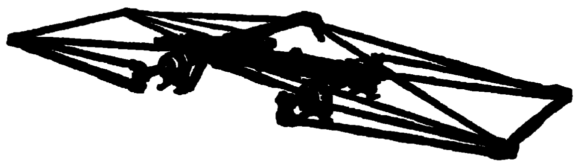


Fig. 122. Pan Pantagraph Collapsed

some lubricant, such as graphite, is usually employed to reduce the wear on the trolley wire and on the collector contact strips.

During earlier days of electrical operation heavy electric trains were usually supplied by a third rail, owing to the inability of the wheel trolley to collect sufficient current for rapid acceleration. With the higher d.c. voltages, however, and by means of sliding pantographs having two collecting pans pressing against two trolley wires, it has been found possible to collect current in any amount required by electric trains. By this method each pantograph, Fig. 122, represents four contact points, between which the current from the trolley wire is divided automatically.

The roller pantograph, Fig. 123, is not considered suitable for very high-speed service on account of the unusually high speed at which the roller must revolve when operating in passenger service. This roller is mounted in roller bearings provided with definite lubrication to avoid the possibility of the roller's ceasing to revolve.

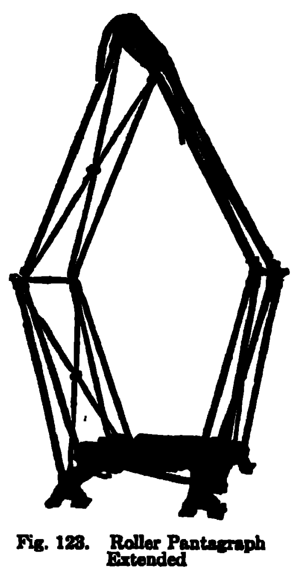


Fig. 123. Roller Pantagraph Extended

Conduit Plow. In congested city streets electric cars are sometimes fed through underground conduits installed between running rails. Current is carried to the trolley car from this feeder by means of a conduit plow, which is attached to the underframe of the car and projects through a narrow slot into the conduit. Two contact points, one on each side of the

plow, engage in a raceway between two conductors, from which the current is passed up through cable connections to the car

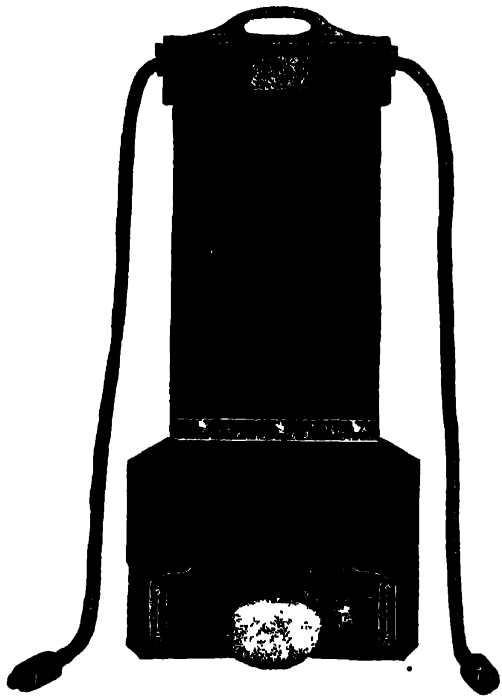


Fig. 124. Underground Conduit Plow Collector

motors. A typical conduit plow, such as is used in the New York City street railways, is illustrated in Fig. 124.

HEATERS

Types. Electric cars are heated by electric heaters (coils of wire of fairly high resistance) and by hot water. The first method, although wasteful of power, is preferred in city cars on account of its convenience.

Electric. Electric heaters are of the open-coil type, Fig. 125, or of the enamel type, Fig. 126. A heater of the open-coil type is merely a number of coils of iron or other high-resistance wire mounted on non-combustible supports, such as porcelain knobs. The coils are placed in a well-ventilated iron case to protect them

TABLE IV

Car Heating Data

	Length of Car Body (ft)	Amperes Switch Positions 1	2	3
Average conditions	14 to 20	3	4	7
	20 to 28	3	6	9
	28 to 34	4	7	11
Severest conditions	18 to 24	4	7	11
	28 to 34	6	8	14

from mechanical injury and to prevent contact with the clothing of passengers.

The enamel heaters have the resistance wire covered with enamel and thus protected from the air. The enamel prevents

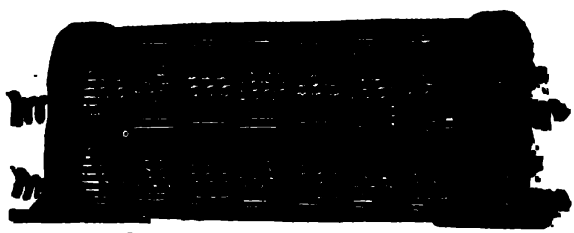


Fig. 125. Open-Coil Type of Car Heater

oxidation and permits the use of higher current densities than the open-coil type without rapid deterioration of the wire. The enamel heaters are, therefore, more compact and are used where there is little space.

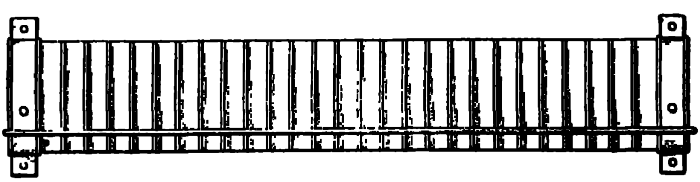


Fig. 126. Enamel Type of Electric Heater

Electric heaters are usually provided with coils of different resistance and, therefore, with different heating ability. It is thus possible to graduate the amount of heat produced by means of switches in the heater circuits. A sample wiring arrangement is given in Fig. 127.

***TABLE V**

Heat Tests on Brooklyn Cars

Cars			Temperature F		Consumption	
Doors	Windows	Contents (cu. ft.)	Outside	Average in Car	Watts	Amperes at 500 Volts
2	12	850½	28	55	2295	4.6
2	12	850½	7	39	2325	4.6
2	12	808½	28	49	2180	4.3
2	12	913¼	35	52	2745	4.5
4	16	1012	7	46	3038	6.
4	16	1012	28	54	3160	6.3

* Foster's "Electrical Engineers' Handbook"

In Table IV is given data from the Consolidated Car Heating Company on the current required to heat cars, while Table V gives results of heating tests made on Brooklyn cars.

Hot-Water. Hot-water heaters are frequently used on large electric cars. Hot-water pipes are placed along the sides of the car and connected with a stove containing hot-water coils at one end

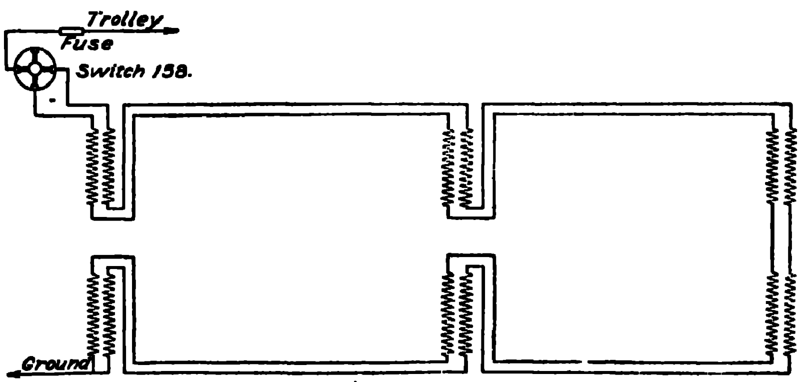


Fig 127. Diagram of Car Heater Circuits

of the car. The water, as it is heated in the stove or heater, expands and consequently becomes lighter per cubic inch or other unit of volume; it, therefore, tends to rise when balanced against the colder water in the car pipes. Hot water leaves the top of the heater, flows up to an expansion tank, then down through the car piping, and back to the bottom of the heater. The car piping slopes continuously down from the top connection to the bottom connection of the heater. At the top an opening to the atmos-

phere is provided through a small water tank, called an expansion tank. This prevents water pressure bursting the pipes as they become heated and allows any steam that may have formed to escape. The most modern hot-water heaters for cars are com-

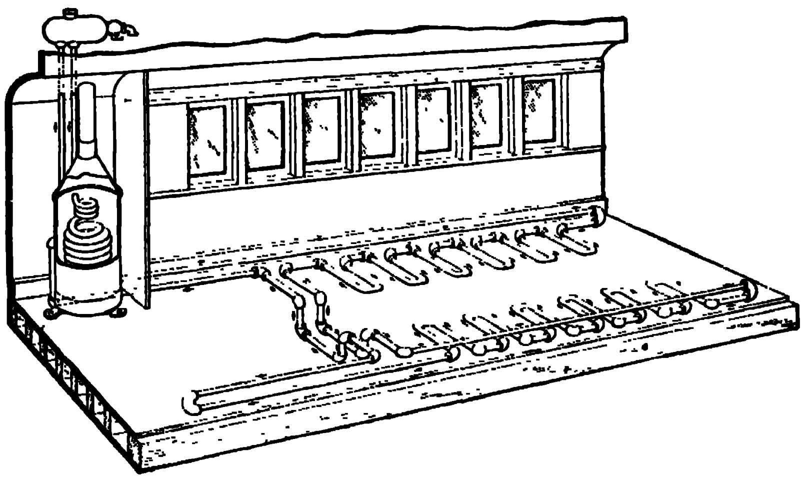


Fig. 128 Diagram of Hot-Water Heating Installation

pletely closed except the ash pit at the bottom and a small feed door in the top. The latter is locked so that the fire cannot come out even if the car is tipped over in a wreck. The pipes of a hot-water heating installation are shown in Fig. 128.

LIGHTING SYSTEM

Incandescent Lamps. The incandescent lamps on an electric car are usually connected in groups of five in series, the lamps being selected for the proper voltage to suit the average conditions on the system. For example, if the trolley voltage is normally 600, the lamps will be designed for 120-volt service; if the normal voltage is only 500, the lamps should be designed for 100-volt operation. Where incandescent headlights are used, the headlight forms one of the series of five lamps. Usually there are two or more lamp circuits in parallel. A sample wiring diagram is shown in Fig. 129.

Lamps for car lighting must be of a particularly sturdy construction to withstand the jars and vibrations incident to the

service. Tungsten lamps have been developed with a heavy well-anchored filament suitable for illuminating electric cars. The characteristic of the Tungsten lamp is such that the wide ranges in voltage common to trolley systems do not cause such wide variations in illumination as is the case with carbon lamps. The efficiency is also much higher, thus saving a material amount of power.

Incandescent Headlights. For incandescent headlights a regular carbon or Tungsten lamp is used, mounted behind a semaphore lens or in front of a shallow parabolic reflector. In some cases it is desirable to obtain an improved illumination by

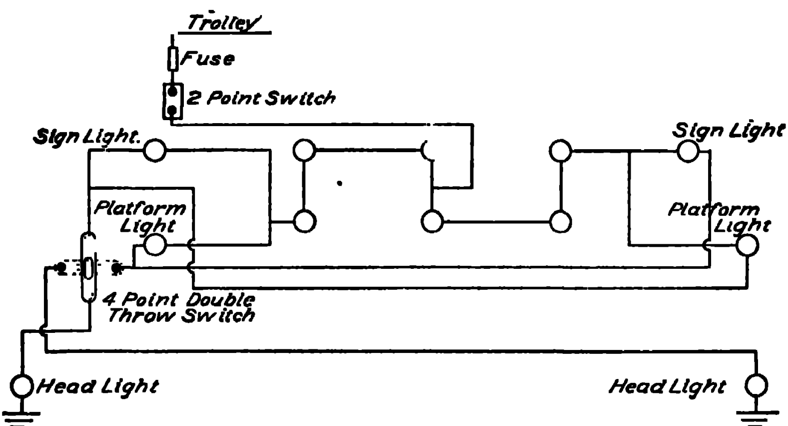


Fig. 129 Wiring Diagram for Car-Lighting System

the use of the concentrated-filament lamp. A cross-section of an incandescent headlight is shown in Fig. 130. The reflector is a drawn-steel jacket enclosing an open aluminum parabolic reflector which is highly polished.

Arc Headlights. On interurban lines it is essential that the headlight be of sufficient power to illuminate the road for some distance ahead in order to give the motorman the greatest possible interval of time in which to stop the car after seeing an obstruction on the track. This point will be appreciated when it is remembered that in order to stop a car traveling at 60 miles an hour, an intervening space of 1750 feet must be allowed. Headlights may be constructed for both incandescent and arc operation, so that an incandescent headlight can be used in the city and an

arc headlight on the outside lines. The arc lamp is usually of the luminous type, similar to the one shown in Fig. 131, in which the lower electrode is of magnetite, which produces a brilliant white arc when heated to incandescence. The lamp is generally of the gravity-feed type, being controlled by a solenoid and plunger and connected in series with a steadying resistance. In Fig. 132 is shown a method of connecting an arc headlight so that the lamps inside the car are utilized as a steadying resistance.

The lower carbon in Fig. 131 has no automatic feeding mechanism, but the position of the arc is adjusted by hand through a friction wheel operated by a knurled head. The operation of the lamp is as follows: the current flows through a controlling resistance, through the carbons and across the arc, through the flexible connecting wire, and through the control magnet coil, all in series. The clutch is a piece of porcelain with a hole slightly larger than the upper carbon. The form of the clutch is seen in the illustration. At one end it is pivoted to a link connecting

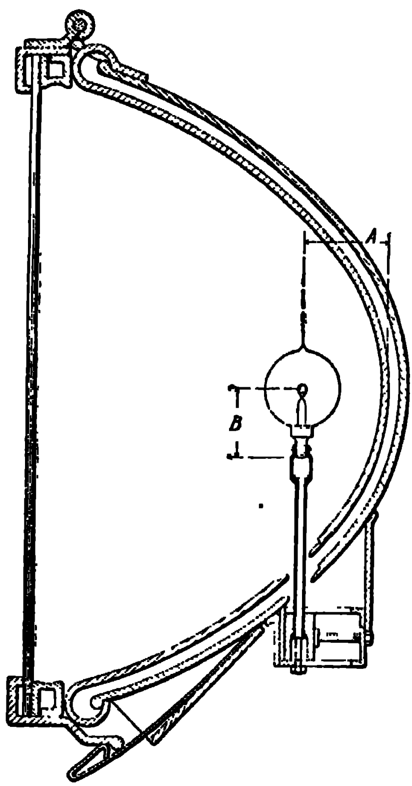


Fig. 130. Section of Incandescent Headlight

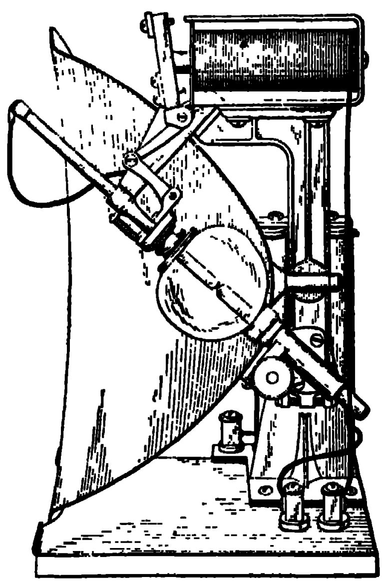


Fig. 131. Section of Arc Headlight

with the lever operated by the magnet core; the other end is held in place by a spring. When the magnet coil is energized by an excessive current, the core is attracted and through the levers one end of the clutch is raised. It binds on the carbon and raises it, thus lengthening the arc. When the arc burns to such a length as to cut down the current by the increase of resistance, the coil releases the core, the clutch returns to the position shown, and the upper carbon slips down until the current is increased sufficiently to raise the clutch again, thus maintaining a constant arc length.

As most interurban cars operate in both country and city and as the arc lamp is very objectionable in the city, a combination of arc and incandescent headlights is employed. The two lamps

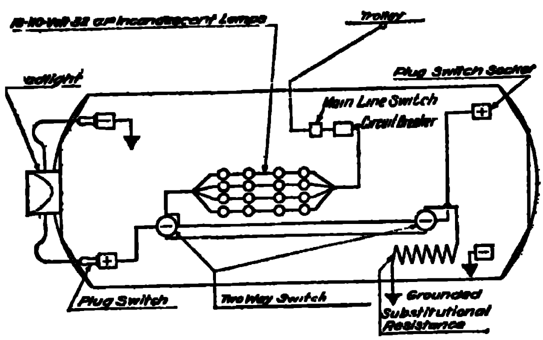


Fig. 132. Connections of Form D Headlight

may be conveniently located in the same reflector, although in this arrangement it is impossible to have both lamps at the focus of the reflector. A two-way switch permits the motorman to switch on whichever lamp is desired.

Motor-Generator Set for Lighting. On some lines where the trolley voltage fluctuates through an unusually wide range it is desirable to install a small motor-generator set on the car, by means of which low-voltage current can be secured for the operation of 32-volt lamps in the car. This set is so constructed that it will give practically a uniform voltage over a wide range in motor speed, owing to fluctuations in trolley voltage. By use of this low potential it is also possible to install the lamps in parallel circuits in the car so that each lamp is independent of the rest of the installation. This scheme has the additional

advantage of permitting the use of low-voltage Tungsten lamps, which have high efficiency and are of much more rugged construction than the 110-volt types.

CAR WIRING SYSTEM

Fire Protection. The wiring diagrams studied earlier in the course indicate the motor and control circuits for handling the propelling equipment of the car. In addition to these circuits, there are heating and lighting circuits, air-compressor circuits, and usually bell circuits. The method of installing the wires for handling these circuits is clearly outlined by the rules of the National Board of Fire Underwriters. These recommendations are outlined with the view to securing the maximum possible protection against fire and are determined partly by the experience of the car operators and partly by suggestions from insurance companies.

As it is customary for railway companies to insure their cars against fire, the insurance companies have practically the same jurisdiction over cars that they have over buildings, since they can refuse insurance which is considered an unnecessarily hazardous risk. Section 40 of the National Electric Code covers car wiring and the equipment of cars. In order that the student may become familiar with this section of the code, it is given in full.

CAR WIRING AND EQUIPMENT OF CARS

The following rules apply to all cars or locomotives used for electric-railway service and cars or locomotives for other railway service which are equipped with electric circuits and operating on either low- or high-potential systems.

a. **Protection of Car Body, Etc.**

1. Where the under side of car bodies is composed wholly or in part of combustible material under which any apparatus is mounted, a protection of *approved* fire-resisting and heat-insulating material not less than ⅛ inch in thickness or sheet iron or steel not less than 0.01 inch in thickness must be provided as follows:

2. Over motor trucks the protection must extend the entire width of the car and lengthwise of the car to a distance of at least 12 inches beyond the area under which the flexible motor leads, contact-shoe leads, brake shoes, and motor, exclusive of gear case, may come in any operating position. In all cases fireproof material or sheet iron or sheet steel must have joints well fitted and must be securely fastened, and the whole surface must be treated with a moisture-repellant paint.

3. Over resistances, contactors, lightning arresters, air-compressor motors, and other electrical apparatus and conductors, except where their casings provide approved protection for the car body, nonmetallic, fire-resisting, heat-insulating material must extend to the edge of the car or not less than 8 inches beyond all edges of the devices.

4. All conductors (except flexible motor leads, leads over grid resistance, and as provided in Section *d*, paragraph 7) on the under side of car bodies must be installed either in *approved* conduit or in *approved*, totally enclosed, fire-resisting ducts. Leads must be brought out of conduits or ducts through *approved* fittings.

b. **Wires, Cables, Etc.**

1. All conductors must be stranded and must comply with the requirements of this Code for rubber-covered wires and cables.

Fixture wire will not be permitted.

The allowable carrying capacity of wires shall be determined by Table A of No. 18, except that motor, trolley, and resistance leads shall not be less than No. 7 B. & S. gage. For heater circuits and arc-headlight and air-compressor circuits conductors shall be not less than 6000 circular mils in cross-sectional area, and for lighting and other auxiliary circuits conductors shall be not less than 4000 circular mils in cross-sectional area.

The leads between the car body and the main motors shall be flexible and triple braided.

The current values used in determining the size of motor, trolley, and resistance leads shall be the per cent of the full-load current, based on one-hour rating of the motor, as given by the following tabulation:

Size of Each Motor	Motor Leads	Trolley Leads	Resistance Leads
75 hp. or less	50 per cent	40 per cent	15 per cent
Over 75 hp.	45 per cent	35 per cent	15 per cent

2. Conductors must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered and covered with an insulation equal to that on the conductors. Joints made with *approved* splicing devices and those connecting the leads at motors, plows, or third-rail shoes need not be soldered.

3. Cable connections to all apparatus, excepting drum controllers, must be made as follows:

Cables not larger than No. 12 B. & S. gage must be attached: (*a*) by having all strands dipped in solder and clamped under a screw head and against a metal base provided with a projection or lug for retaining the cable under the screw head; (*b*) by a flat terminal soldered to the cable and clamped to a base or post by means of a screw or nut; (*c*) by inserting all strands in a hole in a block or post and holding by a set screw; or (*d*) by other approved method of connection.

Cables larger than No. 12 B. & S. gage must be attached: (*a*) by a terminal soldered to the cable and securely fastened to the device by a bolt or screw or by clamping; (*b*) the end of cable may be held by a clamp so designed as to prevent a separation of the cable strands; (*c*) the end of the cable after the insulation is removed shall be dipped in solder and be fastened

into the device by means of at least two set screws having check nuts; or (*d*) by other approved method of connection.

c. Cutouts, Circuit-Breakers, and Switches

1. Cutouts must be of *approved* cartridge or *approved* blow-out type. Circuit-breakers and switches, including oil circuit-breakers and oil switches, must be of *approved* types.

2. All cutouts and switches having exposed live metal parts must be located in cabinets. Cutouts and switches not in iron boxes or in cabinets must be mounted on not less than ½-inch fire-resisting insulating material. which must project at least ½ inch beyond all sides of the cutout or switch,

3. Cutout and switch cabinets must be substantially made of steel not less than $\frac{1}{16}$ inch in thickness or of hardwood. For cabinets containing switches or cutouts having exposed live metal parts the entire inside, including the door, must be lined with an *approved* fire-resisting insulating material not less than ½-inch thick, securely fastened and treated with a moisture-repellant paint.

4. Circuits carrying constant loads, such as lighting and heater circuits, etc., must not be fused at more than the rated capacity of the cables as given in Table A of No. 18.

5. Light, control, heater, and auxiliary circuits may be taken off ahead of the main power cutout, but must each be separately fused.

6. Circuit-breakers may be housed in a cabinet of metal or of wood lined with *approved* fire-resisting insulating material not less than ¼ inch thick. Care must be taken that the arc chute is placed so that the arc will not come in contact with any woodwork or grounded metal. With lined wooden cabinets the conduit carrying the wires must end just outside the cabinet.

7. Where power is derived from both a third rail and an overhead trolley, a switch must be installed by which the third-rail shoe may be cut out when not in use.

d. Conduit

When, from the nature of the case or on account of the size of the conductors, the ordinary conduit and junction-box construction is not possible, a special form of conduit system may be used, provided the general requirements as here given are complied with.

When conduit is used, outlets must be provided with *approved* outlet boxes, or when wires are fully protected from mechanical injury, the outlet box may be omitted and the conduit fitted with an *approved* bell mouth or *approved* bushing.

1. Conduits and outlets and junction boxes must be of approved type. Conduit for lighting, heating, and air-compressor circuits need not be larger than ½-inch electrical-trade size. Where exposed to dampness, the conduit system must be so installed as to exclude moisture from wheel wash and other causes.

2. Conduit must be continuous between and be firmly secured into all outlet or junction boxes and fittings, making a thorough mechanical and electrical connection between same.

3. Conduits, where they enter all outlet or junction boxes and fittings, must be provided with *approved* bushings fitted so as to protect cables from abrasion.

4. Conduit must be permanently and effectively grounded.

5. Junction and outlet boxes must be installed in such a manner as to be accessible.

6. All conduits, outlets, or junction boxes and fittings must be firmly and substantially fastened to the framework of the car.

7. For a.c. circuits carrying over 150 amperes and located wholly below the car body conduit may be omitted.

e. Raceways

Raceways must be of an *approved* type and may be installed only where not subject to moisture. Metal raceways must be permanently and effectively grounded.

f. Lighting and Lighting Circuits

1. Receptacles and clusters must be of approved type.

2. Circuits must be run in *approved* conduit or *approved* metal raceways, except that for circuits of 700 volts or less conductors may be installed in approved nonmetallic raceways.

3. When conduit or metal raceways are used, receptacles or clusters must be mounted on *approved* outlet boxes or in other approved manner, and the exposed metal parts must be thoroughly grounded.

4. When circuits are run in nonmetallic raceways, receptacles or clusters must be mounted on blocks of hardwood or fire-resisting insulating material.

5. Headlight circuits, when under the car body, must be in conduit. Resistance must be well ventilated and mounted as specified in Section *a.* Plugs and plugging receptacles must be of *approved* type.

6. Lamp or voltage regulators and controllers for axle-driven or power-driven generator equipments for car-lighting service must be installed in *approved* cabinets and ventilated.

7. Storage batteries for car lighting or car control must be installed in an approved manner.

g. Heaters and Heater Circuits

1. Heaters must be of *approved* type. Metal enclosures must be thoroughly grounded.

2. Panel heaters should preferably be mounted in metal risers set back at least 4 inches from front edge of seat to prevent pocketing of heated air by clothing of passengers.

The heating element must be located at least 4 inches from all unprotected woodwork. If the woodwork is protected by at least $\frac{1}{4}$-inch thick, approved, fire-resisting insulating material, this distance may be reduced to 2 inches.

3. Heaters for cross seats must be so located that heating element will be at least 6 inches below combustible material of seats, unless under side of seat is protected by not less than $\frac{1}{4}$-inch fire-resisting insulating material or 0.4-inch sheet metal with 1-inch air space over same, when the distance may be reduced to 3 inches.

4. Circuits must be run in *approved* conduit, and connection of wires to heater must be protected from mechanical injury.

h. Auxiliary Motor Circuits

1. Motor frame must be thoroughly grounded. Motors when in a confined space must be in an approved metal box or a wooden box lined with ¼-inch fire-resisting insulating material and ventilated.

2. Circuits under car floor must be run in metal conduit.

3. Air-compressor governor must be of the enclosed type or must be enclosed in an *approved* cabinet or box.

i. Main Circuits and Devices

1. Conductors connecting between trolley base and main cutout or circuit-breakers must have an insulation approved for the voltage carried and, where run lengthwise of the car, must be run on a wooden strip mounted on ⅜-inch filler blocks located at such a distance apart as to allow water to pass freely under it. The running board may be used for this purpose. The trolley lead must be securely fastened to the trolley base and must be arranged to prevent the entrance of moisture where passing through roof.

2. Current collectors, such as trolley stands, pantographs, third-rail shoes, etc., must be supported on well-seasoned and thoroughly painted hardwood or other insulating supports approved for the voltage carried.

3. Conductors connecting between third-rail shoes on same truck must be supported in a hardwood or insulating raceway or in metal conduit. If the conductor is run in conduit, it must be fused as near as possible to the contact shoe before entering the conduit.

4. Conductors on the under side of the car must be run in metal conduit. Junction boxes or other *approved* fittings must be installed where branches in conduit are made. Main cables between controllers (at either end of the car) may be in cable boxes in the interior of the car. Cable boxes, if of wood, must be at least ⅞ inch thick, lined with ⅛-inch fire-resisting insulating material, with *approved* floor bushings.

Cables or power circuits, where exposed under car floor, must be run in metal conduit, terminating with *approved* bell mouths or bushings. Conduits, where they terminate above the car floor must project at least 1 inch above the floor line of the car body or platform.

5. Motor leads where leaving the motor shell must be snugly and well bushed with high-grade rubber bushings. Motor leads must be rigidly supported on the motor frame by hardwood or other *approved* cleats. Motor leads must be connected with cables on car body by *approved* connecting devices. Motor leads must be fastened to car body by hardwood cleats placed on each side of the motor-lead connectors; or motor leads may be connected to cables on car body in an *approved* form of junction box.

6. Resistances must be so located that there will be at least 6 inches air space between resistance proper and the fire-resisting insulating protection of the combustible material of the car. Resistance grids must be thoroughly insulated from resistance frames; and frames must be insulated from supports.

The insulation must be removed from conductors for at least 6 inches back from resistance terminal. The bare stranded wire must be filled with solder to make it rigid.

7. The frames of all electrical apparatus under the car, except the main and auxiliary motors and transformers, may be insulated from the car framing.

8. Metal cases and frames of controllers located above the car floor must be thoroughly grounded.

9. When necessary, guards constructed of sheet metal must be provided to protect the resistances and other devices from wheel wash, dirt, etc.

j. Lightning Arresters

1. Lightning arresters must be so located as to protect all auxiliary circuits in addition to main motor circuits and must be connected ahead of all metal conduit or raceways.

2. Lightning arresters must have an adequate ground connection of not less then No. 12 B. & S. gage wire run in as straight a line as possible to the ground, and must be properly protected from mechanical injury by fire-resisting insulating raceway or wooden raceway.

3. Circuit for lightning arresters need not be run in metal conduit.

k. General Rules

1. Insulating joints must be provided below the top of the car roof in whistle or smoke pipes which project above the level of the car roof, or projecting portions of such pipes must be surrounded by a substantial guard or cage not in electrical connection with such pipes.

2. All coal-burning heating devices must be thoroughly grounded. An adequate insulating cover over hot-water tanks projecting above car roof must be provided.

MECHANICAL AND ELECTRICAL DEVICES

Drawbars and Couplers. As cars are frequently used in trains, some provision must be made for coupling them together. This matter is of such importance that the American Electric Railway Association has given it special attention, particularly with a view to standardizing the heights of couplers so that all cars of a given class may be coupled. In Fig. 133 are shown the arrangements recommended by the Association, not only for couplers but for steps and bumpers.

The coupler for electric cars differs somewhat from that used in steam practice because such cars must round sharp curves, hence the coupler must have considerable sidewise play.

For small surface cars a crude drawbar is usually provided, consisting simply of a straight iron bar pivoted under the car and provided with a cast-iron pocket near the end. A coupling pin, passing through the pocket of one coupler and through a hole in the end of the bar of the other, holds the two cars together.

The requirements of a coupler for heavier cars such as those used on interurban and elevated roads and in subways are more exacting. The ends of the bars are usually pivoted under the car

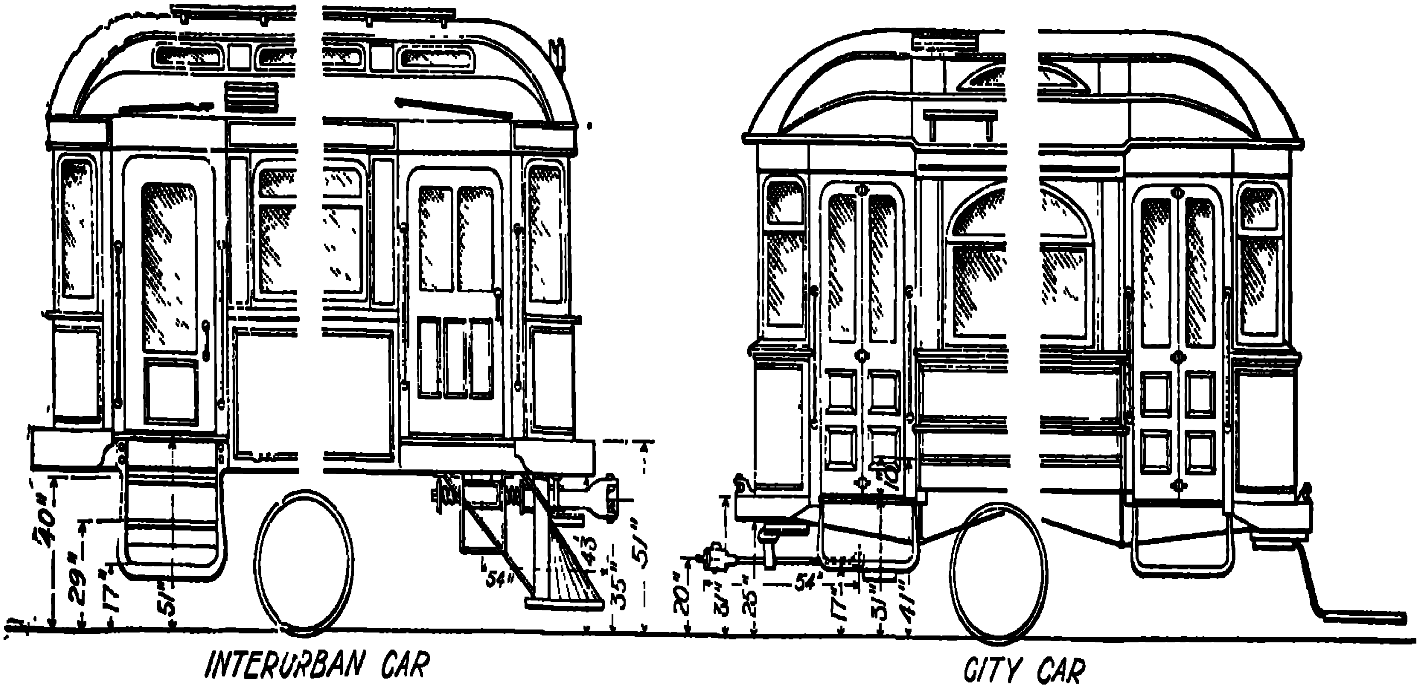


Fig. 133. Details of Coupler, Steps, and Bumpers of an Electric Car

about 5 feet back from the bumper. This is shown clearly in Fig. 134, which represents an adaptation of the standard M.C.B. coupler to interurban electric-railway conditions. This will be recognized as a modified Janney coupler, familiar in steam-railroad practice.

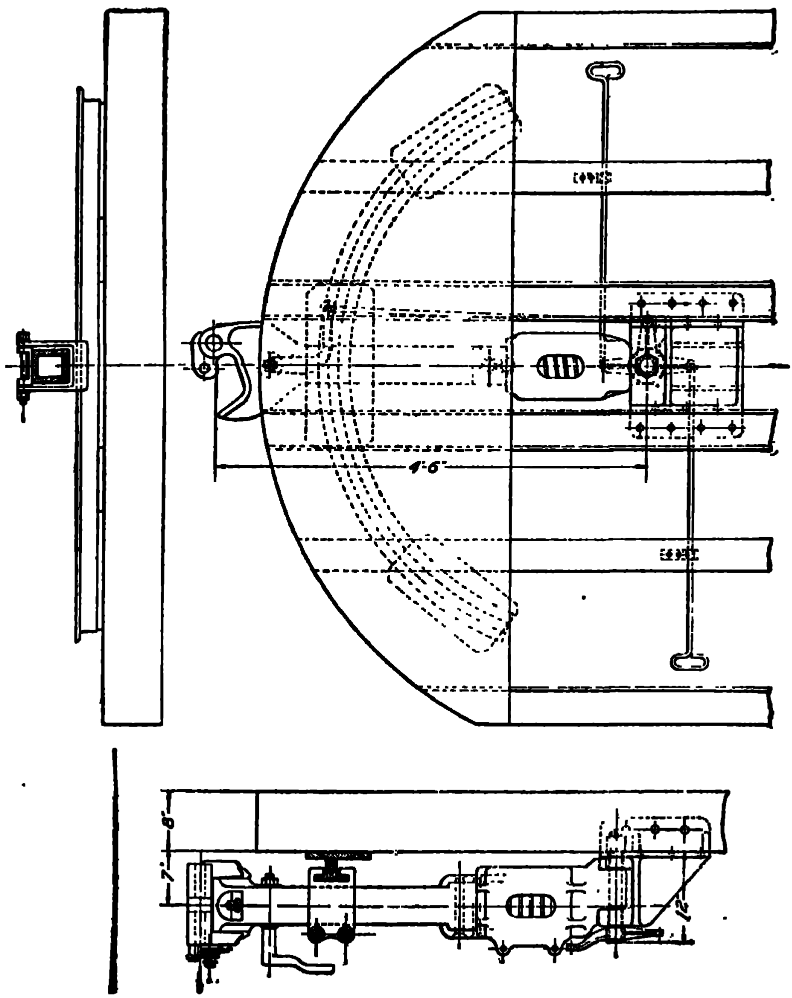


Fig. 134. Plan and Elevation of Standard M.C.B. Coupler

The coupler consists of a steel drawbar about 4½ feet in length. It is pivoted from a strong bracket, which is bolted firmly to the center sills of the under frame. It swivels on a pin carried by this bracket. At the opposite end of the drawbar is a knuckle which

couples with a similar knuckle on the next car. The vertical dimension of the knuckle face is large, say 10 inches, so that cars may be coupled even if their couplers are not exactly on the same

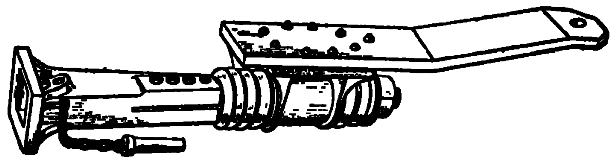


Fig. 135. Drawbar of Simple Coupler

level. The weight of the drawbar at the outer end is supported by a curved carrying-iron bolted under the bumper. This coupler is partly automatic in its action as the two knuckles take the relative positions shown in the dotted lines in the upper part of Fig. 134. They are locked and unlocked by a simple lever system operated by the handles shown in the lower part. It is not necessary for the operator to go between the cars.

An important feature of these automatic couplers is the spring cushion at the pivot end of the bar to prevent excessive shock when two cars come together. It is evident that the couplers have

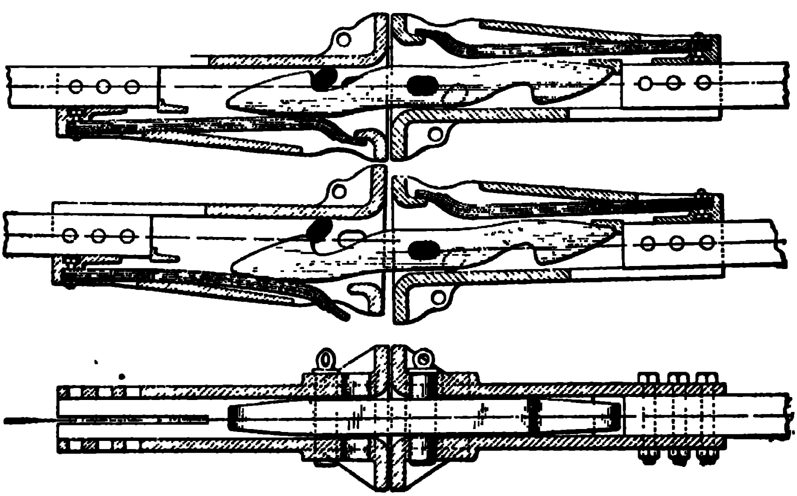


Fig. 136. Sectional Views of Link Coupler

to take the entire shock in this case. The spring cushion is shown in Fig. 134 and still more plainly in Fig. 135, which shows the drawbar of a VanDorn coupler.

As this illustration and Fig. 136 indicate, the VanDorn is a link coupler, which automatically couples and which is ordinarily uncoupled by withdrawing one of the pins. The head consists of

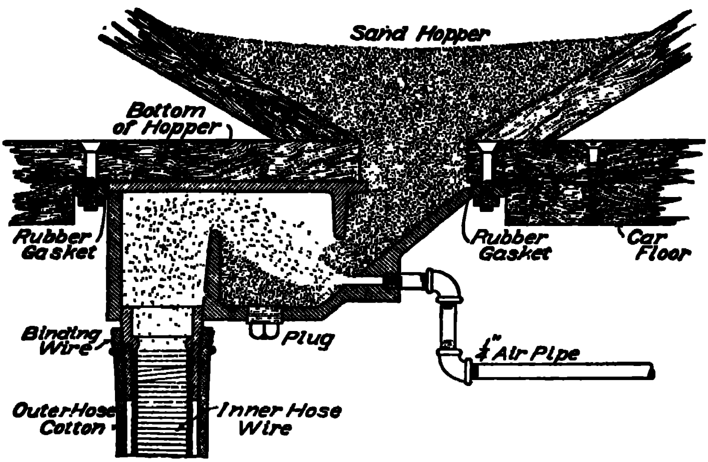


Fig. 137. Section of Pneumatic Sander

a rectangular flat-faced pocket, inside of which is a laminated spring. Holes are provided for dropping the rather flat coupling pins into position. The links and pins are of drop-forged steel and have the form shown in Fig. 136. The uppermost drawing in this illustration represents a section of a complete coupler with the

Fig. 138. Typical Rheostat with Cast-Iron Grids

link firmly locked in position. Before coupling, the pin was placed in the right-hand head in the position shown and then the two heads were brought together. The link pushed its way into the other head, pressing back the spring, as shown in the middle

drawing, and hooking itself over the other pin, which had been previously placed in the position indicated. When hooked over this pin, the coupling of the cars is complete. There are numerous modifications of this coupler but these are the essential features.

Track Sanders. A sprinkling of sand on the rails increases the adhesion between the rails and wheels. Some provision is usually made on cars for scattering sand on the rails immediately in front of the leading wheels. From sand boxes placed under the seats in the smaller cars or on the trucks of the larger ones flexible

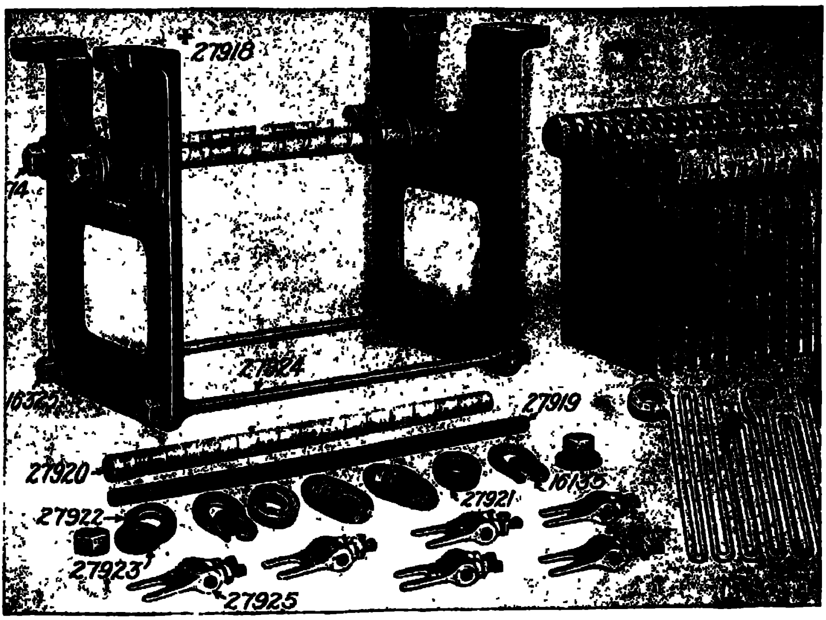


Fig. 139. Rheostat with Grids and Other Parts Displayed

hose or pipes drop within an inch of two of the rail in front of the leading wheels. A valve under the control of the motorman regulates the flow of sand to the rail. Sometimes air pressure is used to blow the sand out of the sand box into the hose. In such a case air pressure is obtained from the air-brake system, and an air valve leading to the sand box is placed in the motorman's cab. A section through a pneumatic sander of this kind is shown in Fig. 137. Sand for use as above described has to be dried very carefully in order that it may flow freely.

Rheostats. The starting resistance is provided by rheostats, which are mounted under the car. An excellent type of rheostat for this work consists of cast-iron grids of the form shown in Fig. 138. Fig. 139 gives details of a rheostat with a slightly different form of grid. Each grid is a zigzag strip of iron with eyes on the ends and in the middle. The eyes form the supports for the grids and at the same time permit convenient connection of the grids in series. The grids are covered with nonoxidizing metal to prevent rust, to which they would be liable on account of their exposed location. The grids are assembled on mica-insulated bolts between end castings. In order to connect them in series, mica insulating washers are placed between alternate eyes on each side and between all the center eyes so that the current is obliged to flow through all the iron strip. Parallel connection of grids as well as series can be made by properly placing the insulating washers. Electrical connection to the grids is made through brass terminals of the form shown. These are provided with prongs which slip in between the eyes at the proper points, being held firmly in place by the clamp bolts.

The cast grids are made in standard sizes having resistances from about $\frac{1}{50}-\frac{1}{8}$ ohm each. Any desired number of grids can be assembled in a frame by using the proper bolt lengths. The low-resistance grid mentioned will carry 75 amperes continuously or 150 amperes in intermittent service, such as is usual in car operation. The high-resistance grid will carry 30 and 50 amperes, respectively. The ventilation of these grids is good, as there is ample air space between the iron strips.

Canopy, or Hood, Switch. An overhead switch, sometimes called a canopy switch, is commonly placed over each street-car platform where a controller is located, usually in the hood, or canopy, above the motorman's head. This is simply a single-point switch that may be used by the motorman to cut the trolley current off from the controller wiring so that the controllers will be absolutely dead. When two switches of this description are used, one on each end of the car, they are connected in series with each other.

Car Circuit-Breaker. Frequently on large equipments an automatic circuit-breaker is provided instead of the overhead

switch. This circuit-breaker can be tripped by hand to open the circuit whenever desired. It is equipped with a solenoid magnet, which can be adjusted so that it will trip or open the circuit-breaker at approximately whatever current it is set for. This circuit-breaker protects the motor and car wiring from excessive current, such as would occur in case of a short-circuit in motors or car wiring or in case the motorman turned on current so rapidly as to endanger the windings of the motors. Circuit-breakers, however, are most commonly used on cars having controllers located at only one end in a motorman's cab. A typical automatic circuit-breaker is illustrated in Fig. 140.

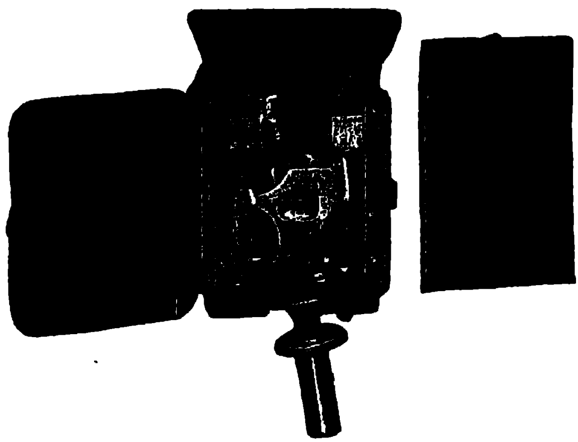


Fig. 140. Typical Automatic Circuit-Breaker

Fuses. A fuse is placed in series with the motor circuit between the trolley and the controller wiring. When circuit-breakers are used instead of canopy switches, the fuse box may sometimes be dispensed with. The fuse box on street cars is usually located underneath one side of the car body where it is accessible for replacing fuses, but when a motorman's cab is used, the fuse may be placed in the cab. The fuse may be of any type in common use, either open or enclosed.

Lightning Arresters. Lightning arresters are used on all cars taking current from overhead lines. The lightning arrester is connected to the main circuit as it comes from the trolley base before it reaches any of the other electrical devices on the car, so that it may afford them protection. One terminal of the lightning

arrester is connected to the motor frame so as to ground it, and the other is connected with the trolley. In most forms of lightning arresters a small air gap is provided, not such as to permit the 500-volt current to jump across, but across which the lightning will jump on account of its high potential. To prevent an arc being established across the air gap by the power-house current after the lightning discharge has taken place and started the arc, some means of extinguishing the arc is provided. In the General Electric Company's lightning arrester the arc is extinguished by a magnetic blow-out, which is energized by the current that flows through the lightning arrester. The instant the discharge takes place the current flows across the air gap. The magnetic blow-out extinguishes the arc, and this opens the circuit, leaving the

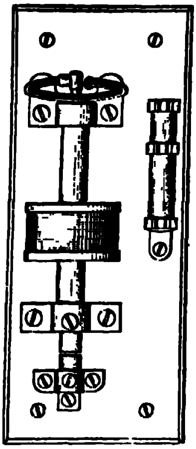


Fig. 141. Typical Form of Lightning Arrester

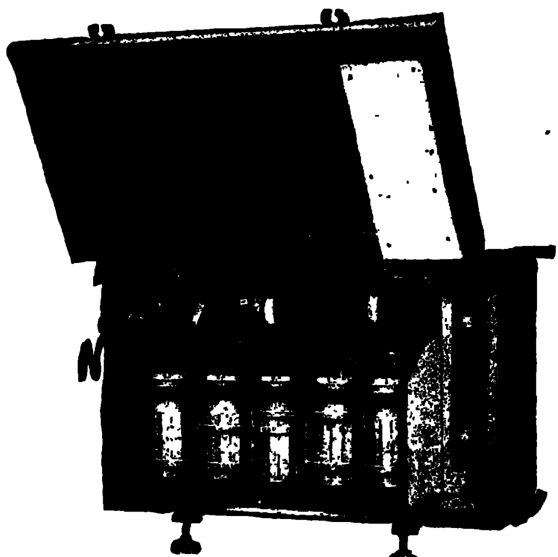


Fig. 142. Aluminum-Cell Lightning Arrester for 1200-Volt Car

arrester ready for another discharge. In the Garton-Daniels lightning arrester, Fig. 141, a plunger contact operated by a solenoid opens the circuit as soon as current begins to flow through the

arrester. This plunger operates in a magnetic field, which extinguishes the arc.

Aluminum-Cell Lightning Arrester. In localities where lightning storms are severe the aluminum-cell arrester is used on trolley cars. This arrester consists of aluminum plates immersed in a suitable electrolyte contained in glass jars, Fig 142. The number of cells is varied to suit the trolley voltage. This arrester works on the same principle as the larger station arresters of the aluminum-cell type. Under normal conditions the arrester has a high resistance and a very small current flows, forming a film of aluminum hydroxide over the surface of the plates. When a high-voltage discharge is applied, however, the film breaks down and the lowered resistance allows the current to pass through the cell to ground. The aluminum-cell type is self-healing and is

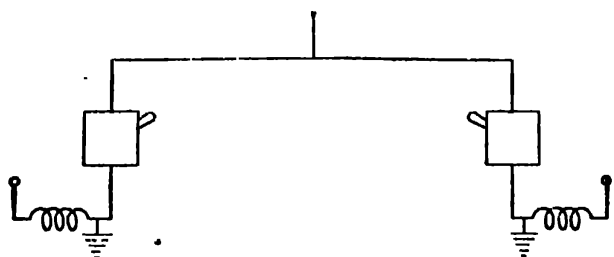


Fig 143. Parallel Connections for Choke Coils and Circuit-Breakers

immediately ready for the next discharge. The action of the arrester is thus analogous to a steam safety valve. This arrester requires occasional inspection and costs more but is more reliable than other types.

Choke Coil. A choke coil, consisting of a few turns of wire around a wooden drum, is placed in the circuit leading to the motors at a point just after it has passed the lightning-arrester tap. This choke coil is for the purpose of placing self-induction in the circuit so that the lightning will tend to branch off through the lightning arrester and to ground rather than seek a path through the motor insulation to ground. Often, however, the choke coil is omitted, the coils in the circuit-breaker and the blow-out coil in the controller being depended upon to prevent the lightning charge from passing.

Wiring of Circuit-Breakers and Canopy Switches. The methods of wiring circuit-breakers and canopy switches for double-end cars are shown in Figs. 143, 144, and 145.

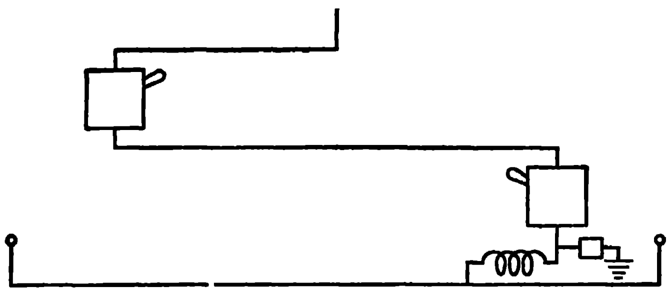


Fig. 144. Diagram of Series Connections for Hand-Operated Circuit-Breakers

In the parallel connection, Fig. 143, the trolley leads after passing through the choke coils go directly to the blow-out coil of the controllers. Aside from the fact that two lightning arresters and choke coils are required, this method is preferable for automatic circuit-breakers.

Hand-operated circuit-breakers connected in series are illustrated in Fig. 144. This method is used where nonautomatic breakers are employed, but for automatic breakers it has the objection that an overload would throw the breaker, if set at the lowest point. This breaker might be at the opposite end of the car from the motorman, in which case he must go the length of the car to set it.

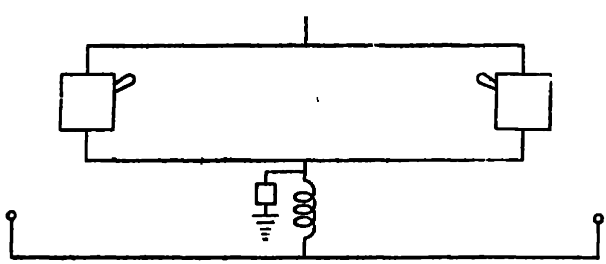


Fig. 145. Parallel Connections of Circuit-Breakers, Requiring But One Lightning Arrester

A method of parallel connection requiring but one lightning arrester is given in Fig. 145. The method, however, gives the motorman no assurance that by throwing the breaker located

above him the power will be cut off, for the rear breaker may have been left set.

MECHANICS OF CAR MOVEMENT

Analysis of Car Movement. A car has to be (1) brought up to speed, or accelerated; (2) maintained at speed; and (3) brought to rest, retarded, or decelerated. In addition it may be allowed to coast, or run without power.

There are several resistances which must be overcome in the foregoing operations, namely, friction* (including resistance due to curves); grade resistance; and resistance to acceleration.

Friction. Friction requires a tractive effort which increases somewhat with the speed. An average value for electric cars is about 20 pounds per ton (2000 pounds). Where great accuracy is desired in this item, it is necessary to use a formula which has been derived from experiment. Such a formula is the following, worked out by W. N. Smith.

$$R=3+0.167V+0.0025\frac{A}{T}V^2$$

wherein R is the resistance in pounds per ton; V is the speed in miles per hour; A is the vertical cross-sectional area of the car in square feet plus one-half the vertical area from car floor to rails; and T is the weight of the car in tons of 2000 pounds each.

Example. What tractive effort will be required to maintain a uniform speed of 35 miles per hour on a level track with a 20-ton car whose cross-sectional area is 100 square feet? What mechanical power is developed at this speed?

Applying the Smith formula gives

$$R=3+(0.167\times35)+(0.0025\ \frac{100}{20}\times35^2)=24.15\text{ lb. per ton}$$

$$\text{Total tractive effort}=24.15\times20=483\text{ lb.}$$

The power is the number of foot pounds per minute divided by 33,000 (the number of foot pounds per minute in 1 hp.).

$$\text{hp.}=\frac{483\times35\times5280}{33000\times60}=45.1$$

Ans. 483 lb.
45.1 hp.

* The frictional resistance opposing the motion of the car is made up of several components flange, a gearing and bearing friction, and air resistance. The last increases rapidly with the speed, while the others are nearly independent of it. All of these differ from sliding friction, such as that between brake shoes and wheels, which decreases as the speed increases.

Curve Resistance. Curve resistance may sometimes be of importance. The usual method of allowing for it is to consider that there is a certain amount of resistance per ton per degree of curvature, say 0.7 pound. The number of degrees of curvature is the angle between two radii of the curve drawn at the ends of a chord 100 feet in length. In terms of the radius r the angle of curvature is twice the angle of which the sine is $\frac{50}{r}$. This relation is shown diagrammatically in Fig. 146.

Example. What is the curvature of a curve the radius of which is 100 feet? What additional resistance is caused by this curvature?

As explained

$$\text{Sine of } \tfrac{1}{2} \text{ the angle} = \frac{50}{100} = \tfrac{1}{2}.$$

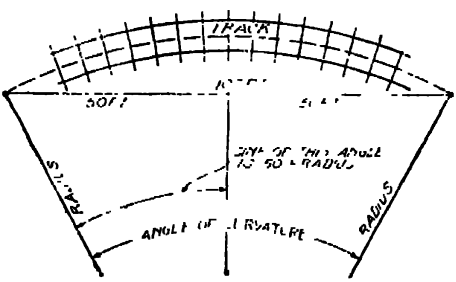


Fig 146 Graphical Determination of Track Curvature

From the table of sines this is found to be the sine of 30 degrees. The angle of curvature is, therefore, 60 degrees.

The additional resistance is as follows:

$$R = 0.7 \times 60 = 42 \text{ lb. per ton}$$

Ans. 60 degrees
42 lb. per ton

Grade Resistance. Grade resistance is simply the tractive effort in the direction of car motion necessary to overcome the effect of gravity. It is numerically equal to the product of the weight of car in pounds and the grade in per cent divided by 100.

Example. What tractive effort is necessary to overcome grade resistance on a grade of 10 per cent with the 20-ton car used in previous examples?

$$R = 20 \times 2000 \times \frac{10}{100} = 4000 \text{ lb., or } 200 \text{ lb. per ton}$$

Ans. 200 lb. per ton

Acceleration Resistance. A body resists any change in speed on account of the property of inertia. Thus, if at rest, it tends to remain so; if moving with a given velocity, its tendency is to maintain this velocity. By definition, *force is the cause of acceleration of a mass.* The unit of force is that which will produce unit rate of acceleration (in other words, unit rate of increase in speed)

in a unit of mass. But what is a unit of mass? This is a matter which has to be arbitrarily chosen by the government. The unit so chosen is the avoirdupois pound. The corresponding value of the unit of force will depend upon the kinds of units in which the acceleration is expressed. It is customary in this country to express acceleration in feet per second per second. That is, if the velocity of a body increases 1 foot per second every second, it may be said to have unit acceleration. A force which produces this acceleration in a mass of 1 pound is sometimes called a poundal. The poundal, while a good scientific unit of force, is not in common use. It is the custom to speak of force in pounds, using the word "pound" here to mean the force with which the earth attracts a mass of 1 pound. This force is not proportional to the mass, for it is different in different places. It is greater at the north pole than at the equator, for the radius of the earth is shorter at the former. One pound of mass would weigh very little on the moon if the weight were determined by a spring balance calibrated or graduated on the earth, etc.

It is found by experiment that the earth, in most inhabited parts, exerts such a force on 1 pound of mass as to impart to it an acceleration of about 32.2 feet per second per second. If, therefore, it is desired to use the expression "pounds of force," meaning by "a pound of force" the force exerted by the earth on 1 pound of mass at a given point on the earth's surface, it must be remembered that this is equal, in poundals, to the acceleration due to gravity at that point. For practical purposes it can be assumed that a "pound" of force is about 32.2 poundals. It is in this sense that the horizontal effort of a motor has been used up to this point.

Example. A street car weighs 40,000 pounds. It is desired that it reach a speed of 20 miles per hour in 20 seconds. How much force must be applied in poundals; in pounds?

Apply the formula

$$F = M \times a$$

in which mass M is in pounds and acceleration a is in feet per second per second.

$$F = 40000 \times \frac{20}{20} \times \frac{5280}{3600} = 58667 \text{ poundals}$$

The corresponding force in pounds on most parts of the earth's surface is

$$F=\frac{58667}{32.2}=1821 \text{ lb.}$$

Ans. 58667 poundals
1821 lb.

In railway work it is usual to use as a practical unit of acceleration 1 mile per hour per second, and in the preceding example the acceleration was 1 mile per hour per second. The student must be careful to reduce the acceleration to feet per second per second in using the number 32.2 because this is the acceleration due to gravity in feet per second per second.

Braking. In bringing a car to rest the same principles apply as in acceleration. The tractive effort exerted by the brakes in deceleration is the tangential frictional force on the brake shoes if it is assumed that the wheels do not slip on the rails. The formula used in determining the accelerating force is applied in this case as well, but it must be remembered that the decelerating force is in a direction opposed to that of the motion of the car. The force found by the formula does not have to be all supplied by the brakes, for the friction of the bearings, etc., assists the brakes in bringing the car to rest. It must not be forgotten that the decelerating force as calculated is gross. Also, any resistance which has to be overcome must be added to the decelerating force.

Examples. 1. What tractive effort must be exerted by the brakes to bring the 40,000-pound car to rest from 20 miles per hour in 20 seconds?

Applying the formula gives the decelerating force as 58,667 poundals, or 1821 pounds. If it is assumed, for convenience, that the friction is 20 pounds per ton, a total of 400 pounds, the net force which must be applied by the brakes is 1821−400, or 1421 pounds.

Ans. 1421 lb.

2. Determine what total force is available to bring the car to rest going up a 5-per cent grade with the same force as before applied by the brake shoes.

Grade resistance, 40000×0.05	2000 lb.
Friction resistance, 20×20	400 lb.
Deceleration resistance	1421 lb.
Total force available	3821 lb.

Ans. 3821 lb.

3. What time would be required to bring the car to rest on a 5-per cent grade without application of the brakes?

It has been seen that the gross decelerating force needed to bring the car to rest in 20 seconds is 1821 pounds. But the grade gives 2000 pounds and the friction 400 pounds, a total of 2400 pounds, when but 1821 are needed. Evidently the car will come to rest in less than 20 seconds. Applying the original formula, the rate of deceleration corresponding to 2400 pounds retarding force is

$$a=\frac{2400\times 32.2}{40000}\times\frac{3600}{5280}=1.32 \text{ miles per hr. per sec.}$$

At this rate the car would lose a speed of 20 miles per hour in

$$t=\frac{20}{1.32}=15.2 \text{ sec.}$$

Ans. 15.2 sec.

In the calculations a uniform deceleration is assumed for simplicity of calculation, and no great error is involved in so

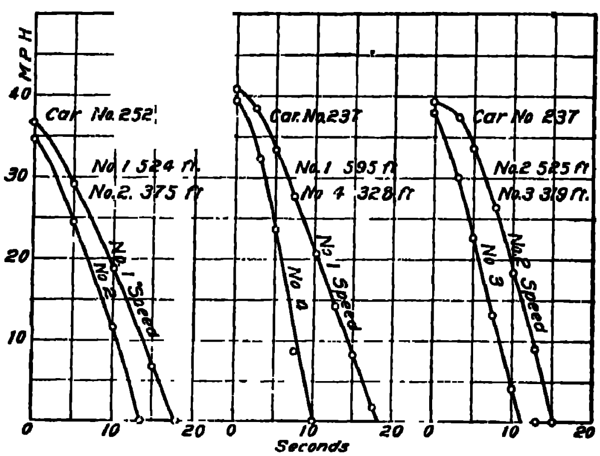


Fig 147. Acceleration Curves

doing. It is interesting, however, to note the actual values obtained from tests. In Fig. 147 are shown the results of such tests. The curves illustrate the important fact that the speed falls off more slowly at high speed, owing to the lower coefficient of friction. With air brakes it is possible to so graduate the air pressure as to produce a practically uniform deceleration if there is any particular reason for having this. The curves show clearly the duration and the distance of braking in each case. The very quick stops, or emergency stops, show what can be done if necessary, although such stops are uncomfortable for the passengers

and racking to the equipment. The rate of braking in these cases averages 3.3 miles per hour per second, while that for the slower stops is 2.3 miles per hour per second. The gross braking forces are, respectively, 120 and 84 pounds per ton.

Coasting. Whenever a motorman finds that he can make satisfactory speed without power, he cuts the latter off and "coasts," or "drifts." The car loses speed by the process, and this loss of speed can be calculated by means of the acceleration formula. For example, if the car is on level tangent track, the decelerating force is simply the friction. This has been assumed to be 20 pounds per ton. If this be assumed constant, the total decelerating force is 400 pounds, from which the rate of deceleration is calculated as 0.22 miles per hour per second. The car will lose 1 mile per hour of speed every 4.54 seconds.

Applications of Principles of Mechanics to Series Motors Mounted on Cars. In practice it is impossible to secure uniform acceleration in a car because the counter-e.m.f. of the motors increases with the speed and cuts down the current. If the current could be kept uniform, it would be possible to apply a constant *gross* accelerating force. Even then the *net* accelerating force would not be constant because the frictional resistance increases with the speed. For the present the latter item will be neglected, however, as it is not of very great importance except in high-speed cars.

The problem is now to determine a curve between time and speed for a given equipment by combining the principles already carefully studied separately.

Acceleration Curves. Referring now to the curves of the motor, Part I, Fig. 48, it is evident that for every current there is a corresponding tractive effort with the given gear ratio and diameter of wheels. The motorman controls the amount of the starting current by the speed at which he "notches" out the starting resistance. In the automatic multiple-unit control systems this is done by the throttle relay automatically. A good motorman should be able to cut out the resistance on his car at such a rate as to maintain the current *per motor* at a fairly uniform value. Of course, in the parallel position the car draws approximately twice the current that it does in the series position. Some cars

do not draw uniform current even with the best of care on the part of the motorman. This is due to the incorrect arrangement of the resistances on the various notches, which should be corrected to ensure the best results.

After the motorman has cut out all the resistance he has no further control of the acceleration, and the current falls off as the counter-e.m.f. of the motor rises with increase of speed. The problem is to determine the rate of acceleration at various parts

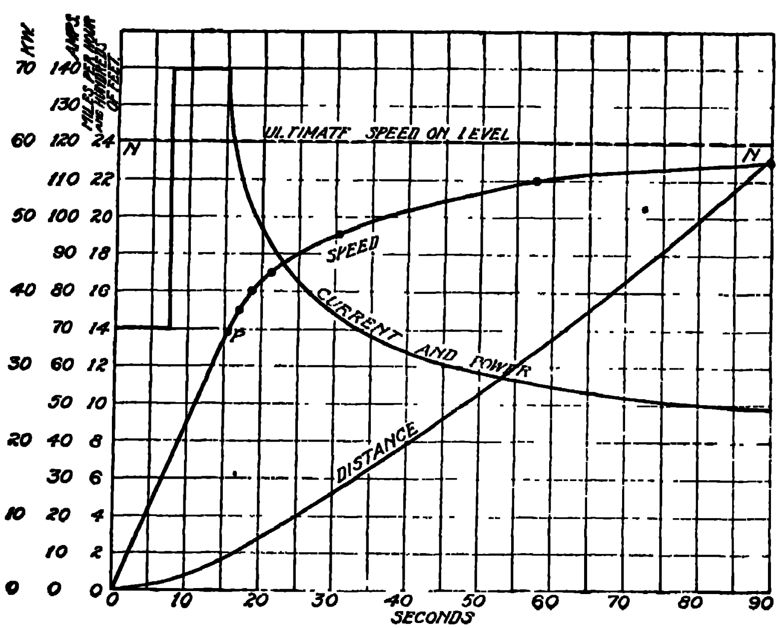


Fig. 148. Speed Curves

of the speed curve and from this to determine the speed at the various points.

In Fig. 148 is shown such a curve. It is divided into two parts: (1) where the speed increases uniformly with time (constant acceleration); (2) where the speed increases more slowly owing to the decrease in current (decreasing acceleration).

Assume that the starting current allowed is 70 amperes per motor. From the motor curves, Part I, Fig. 48, this is found to correspond to a tractive effort of 1030 pounds. If two of these motors are put on the 20-ton car, the total tractive effort for the

two motors is 2060 pounds. Assume that the resistance due to friction is 20 pounds per ton and that the car is on level tangent track. No allowance need then be made for curve or grade resistance.

Applying the acceleration formula, page 141, after deducting 400 pounds for friction, the acceleration is 0.91 mile per hour per second; that is, the speed will, for example, increase by 9.1 miles per hour in 10 seconds. A straight line can be drawn through 0 and the speed at 10 seconds, giving the slope of the first part of the curve, Fig. 148.

Next determine how long this acceleration can be kept up. When the motorman has cut out all the resistance, the speed must correspond to the current as given by the current-speed curve. This is not true while the resistance is in series with the motor, for the resistance cuts down the natural speed for a given current. Therefore read on the diagram the speed corresponding to the assumed starting current, 70 amperes. In the assumed case this is 14 miles per hour, and prolonging the line to the point P shows that the uniform acceleration has continued for 15.4 seconds.

Next determine, point by point, the shape of the speed curve beginning at the point just obtained. This must be done graphically. Assume an increase of speed to a value slightly above the first speed, say 15 miles per hour. During the brief time in which the speed has been increasing the average speed has been

$$\text{Average miles per hour} = \frac{14+15}{2} = 14.5 \text{ miles per hour}$$

Looking now at the motor curves, Fig. 48, Part I, it is found that the current corresponding to this average speed is 60 amperes and the tractive effort is 840 pounds per motor. The corresponding acceleration is 0.70 mile per hour per second. Beginning with point P, lay off a straight line at such an angle as to correspond to the calculated acceleration. It is assumed here that the acceleration will remain uniform during this short period. Continuing in this way step by step, finally an approximate form of the speed curve is obtained. With a French curve these points can be connected by a smooth line. For the most accurate work the

points should be chosen very close together in the part of the curve where it is bending rapidly.

The dotted line *NN*, Fig. 148, is the ultimate speed of the car after all the acceleration is over. This is determined by assuming that all the tractive effort is used up in friction resistance, the speed being then read directly from the curves. In this case it is 24 miles per hour.

Distance Curve. The speed curve leads directly to the distance curve, for, as distance is the product of speed and time, the distance up to any time is the area under the speed curve up to that time; in other words, it is the product of the time and the average speed. The area can be determined in various ways, for example, by counting the squares under the curve when it is plotted on cross-section paper.

Current Curve. Up to the point where resistance is all cut out the current has the assumed value per motor. In practice it is not uniform but follows a zigzag line while the controller handle jumps from notch to notch. Its average value is, however, that from which the acceleration was calculated. At any other time the current is obtained from the current-speed curve of the motor direct, and it has been plotted for the assumed case in the illustration.

Power Curve. As the e.m.f. is constant, it is possible to obtain the power at any time by multiplying together the current and the e.m.f. This gives the power in watts, from which the kilowatts or electrical hp. can be derived by multiplying by the proper constants.

Data from Road Tests. In Fig. 149 are given in graphical form the results of a test of the equipment of an interurban car, made in regular service. It is especially valuable in permitting a comparison of the forms of the curves as calculated and as obtained under service conditions. The upper line shows the line volts, which are the same as the motor volts when the motors are in parallel without starting resistance. The motor volt line indicates how the e.m.f. across the motor terminals increases as the starting resistance is cut out. The motor ampere line, on the other hand, coincides with the car ampere line when the motors are in series, for in this case the same current flows through both

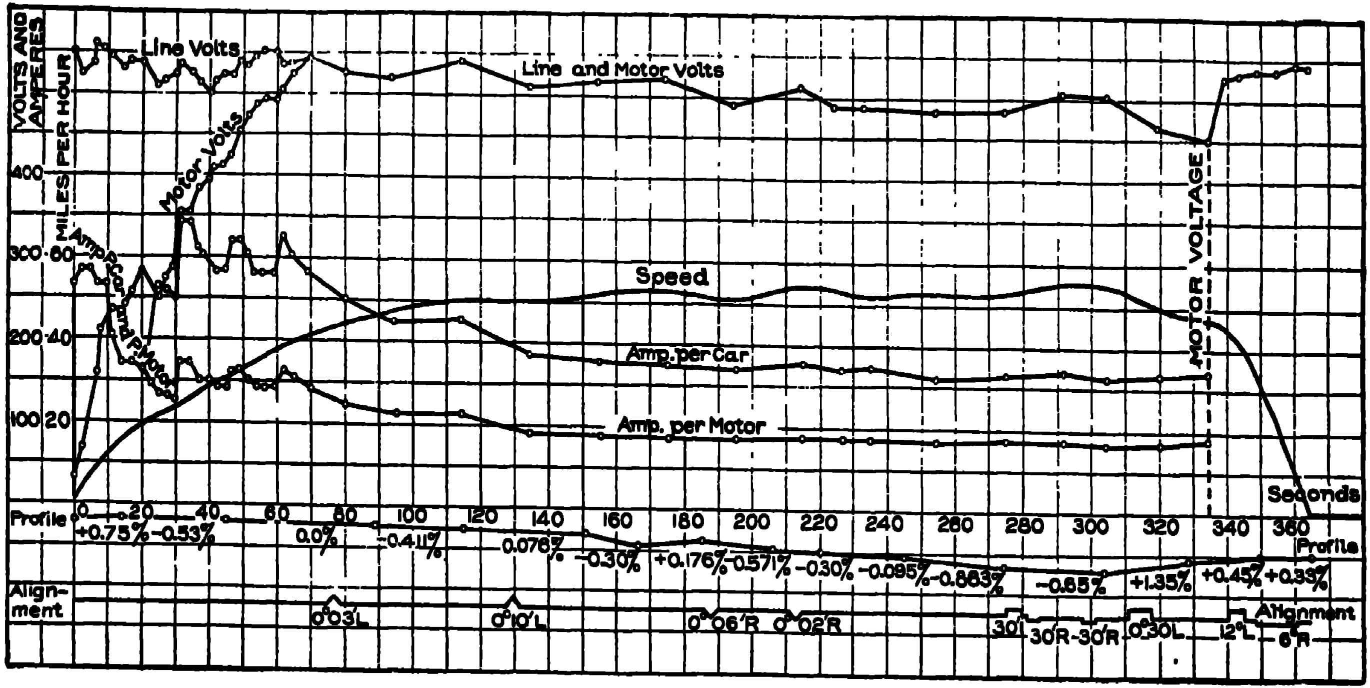


Fig. 149. Graphical Representation of Road-Test Data

motors. The speed line is wavy on account of the change in profile, but it is fairly constant after the period of acceleration is over. It will be noted that there is not the same form of acceleration curve as was obtained by calculation, but a glance at the *Current Per Motor* line will show why. The current per motor was not kept constant by the proper manipulation of the controller. The lower lines show the profile and alignment. The profile shows the grades upon which the car was operating at the times indicated at the base of the chart. The grades are marked in per cent, the sign + being used to designate an upgrade and the sign − a downgrade. The track alignment shows where the curves are located, the degrees of the curves, and the direction of their deflections.

MAINTENANCE OF ROLLING STOCK*

Importance of Repairs. In order to ensure the best service from the car equipment, it must receive careful inspection and repair. Oil requires replacing, brushes must be renewed, etc. Repairs of all kinds must be made promptly to prevent further injury to the equipment.

Oiling. Proper bearing lubrication is of prime importance because a dry bearing will not only ruin itself but it will cause waste of power. Good modern practice seems to favor oiling on a mileage basis, the number of miles between oilings depending upon the make of motors, as the later types have better accommodations for the oil. The armature-bearing mileage will vary from 500 to 1000 for the older motors and may be as high as 3500 in the newer ones. The axle bearings will operate from 1000 to 2000 miles between oilings.

INSPECTION

Inspection Rules. It is not good practice to wait until a serious defect develops before making repairs to an equipment. Regular inspections will show incipient faults and render their repair easy and cheap. As an evidence of the importance of inspection work the following extract is made from the 1909 report of the Committee on Maintenance of Equipment to the American Electric Railway Engineering Association.

INSPECTION WORK

The slighting of inspection work will cause serious interruption to traffic. Worn and flat trolley wheels cause arcing that burns the overhead wire; dry trolley-wheel bearings cause cutting and shorten the life of the wheel; a pole put in with the wheel set at an angle causes the trolley to jump at the switches and may pull the trolley base off the car or pull the overhead wire down and, in addition to the damage caused, endanger life.

The improper fastening of poles in their bases may be the cause of accidents, and if the spring tension is weak, it causes undue arcing and increases the wear on both wheel and wire. If the base is neglected and becomes dry, the trolley runs hard, causing jumping at switches and trouble without limit. Poor contact at the base causes the wire to burn off. Leaky roofs ruin car ceilings, are bad for seats, and generally uncomfortable for passengers. Broken glass is a frequent cause of accidents. Bolts, nails, and screws, if projecting from floor or any part of woodwork, sometimes result in torn clothes and falling passengers. Extended step-treads sometimes strike vehicles, resulting in splinters and sharp edges and their accompanying dangers.

If cars are allowed to go into service with dirt or grease somewhere on the inside, the company may have to pay a bill.

Controller rolls, contacts, and bearings, if allowed to become dry, will cut and cause short-circuits; the roll will work hard and the motorman may not be able to tell distinctly whether or not he is stopping on the points; contact fingers may be set too low, and sometimes the set nut, if left loose on the adjusting screw, works out and the finger drops down and jams on the roll contact. Controller handles, if neglected, become worn and may not turn the roll to the last point; then running on the resistance, burning out a rheostat, and danger of fire may follow.

Neglect of the oiling of motor bearings and car journals is probably the most expensive of all slighted inspection, because it causes the bearings to heat and the armature to go down on the pole pieces.

Lack of care in inspecting motor terminals when connecting up may result in a broken wire in a short time.

Bolts left loose in the armature and axle caps; cotters left out of bolts and hinge pins; brush-holder hammers left up; carbons not cleaned and sticking in their holders; weak springs; failure to tighten bolts and screws at yokes; oil and dust accumulated on brush holders and yokes until they short-circuit and ground; neglect to oil and pack truck journals; brasses allowed to wear down, causing hot journals; bolts in the trucks not kept tightened, wearing face and holes so that later they cannot be kept tight—all these are points that must be carefully watched to ensure the best results.

Tight brakes frequently cause the loss of armatures, which may be blamed upon the lubricating system. Improper adjustment and setting of shoes causes them to flange and to lose a large per cent of their life. Worn and neglected hangers cause brakes to shudder and chatter. Cotters left out of shoe pins and neglected lever pins may cause serious damage and accident. Leaks in the air system not discovered result in overworking the compressor. Neglected brake valves cause the seats to cut. Cleaning and oiling, etc., brake

cylinders and a thousand and one other little jobs should not be neglected. Such neglect is always serious and may be dangerous. It has a direct bearing on expense. Quite a common practice among repair men is to patch up trouble and fail to give the car and motors a careful inspection so that further early trouble may be avoided. Lack of inspection is decidedly detrimental to best economy.

LOCATING DEFECTS IN MOTOR AND CONTROLLER WIRING

Causes of Defects. Defects in the wirings are due either to open circuits or to short-circuits. Open circuits make themselves evident by the failure of the current to flow when the circuit is closed; short-circuits usually make themselves evident by the blowing of a fuse or the opening of the breaker. The point of the short-circuit or ground can be located roughly by noting on what controller point the fuse is blown. Accurate location can be made by cutting out the motors, disconnecting, etc., according to directions in the following pages. The tests outlined apply particularly to the K type of controller with two-motor equipment.

Tests for Open Circuits

No Current on First Point. With an open-circuit wiring anywhere between trolley and ground no current will flow on the first point. Open circuits are most likely to occur in the motors, and these may be tested first. However, one open circuit in an armature will not stop the current.

To test the motors, open the breaker and put the controller on the first multiple point. Then flash the breaker quickly. A flow of current indicates that one or the other of the motors has an open circuit. In the series position this open circuit prevents the flow, but in multiple current the current flows through the other motor. The one at fault can be quickly located by returning the controller to the off position and cutting out one or the other of the motors by means of the cutout switch and then trying for current. The car can in any event be operated by means of the remaining motor. On returning to the shop the open circuit can be determined definitely by the use of the lamp bank.

No Current on First Point Multiple. If no current flows when the breaker is flashed on the parallel point, it is reasonable

to conclude that the motors are all right and that the open circuit is elsewhere. As there is a path through each motor normally, there must necessarily be an open circuit in each one to stop the current. It is hardly probable that such a coincidence would occur.

Series Resistance Points after Trying First Point Multiple. After failure to find the fault in the motors the controller should be placed on progressive series-resistance points and the breaker flashed on each one. If current is obtained on any point, the open circuit is in the resistance or the resistance lead just behind the one being used. Special care should be used to flash the breaker quickly, for otherwise the fuse may be blown. If no current is obtained on the series-resistance points, the open circuit is outside the controller and the equipment wiring.

The tests indicated are sufficient for the motors, controllers, and resistance wiring. If no current is obtained on any of them, the trouble is evidently caused by a poor rail contact, a ground wire off (if both motors are grounded through the same wire), or an open circuit in the blow-out coil, at the lightning arrester, at the circuit-breaker, or on top the car.

Use of Lamp Bank. None of the tests applied locate the open circuit definitely, but this can easily be done in the shop or wherever a lamp bank is at hand. Connect one terminal of the lamp bank to the trolley just behind the circuit-breaker and the controller on the series first point, then with the other terminal begin at the ground and trace backwards up the circuit until the lamps fail to light. The path in a K type of controller is readily traced with the help of the controller diagram, Part I, Fig. 59.

Tests for Short-Circuits

Procedure. The location of short-circuits is tedious. The blowing of the fuse or opening of the breaker will locate them as shown later. The separate tests can then be followed until the location is definite. These tests are especially adapted to cases on the road or where no facilities for testing are at hand. Rather than to blow fuses as frequently as indicated it would in most cases be better to place a lamp bank across the open circuit-breaker and note the flow of the current by the lights.

Fuse Blows when Trolley Is Connected. This indicates that the trouble is due to one of the following causes:

(1) Grounded controller blow-out coil
(2) Grounded trolley wire or cable
(3) Grounded lightning arrester

The blowing of the fuse immediately on closing the overhead switch or circuit-breaker, when the controller is on the off position, indicates that the fault exists somewhere between the circuit-breaker and the upper, or trolley, finger of the controller.

Should the defect occur during a thunderstorm, it may be presumed at once that lightning has grounded the blow-out coil of the controller.

Fuse Blows on First Point. In this case one of the following conditions exists:

(1) Grounded resistance near *R1*
(2) Grounded controller cylinder
(3) Bridging between sections of cylinder

When the controller is on the first point, all the wiring of the system with the exception of the ground wire for *No. 1* motor is connected with trolley. But a defect in the wiring beyond the resistance will not show itself on the first point by an abnormal rush of current because the resistance of the rheostats is sufficient to prevent any excessive flow of current.

The resistance and leads and the controller cylinder are the only parts to be tested when the fuse blows on the first point.

Fuse Blows on Third or Fourth Point. This indicates one of the two following causes:

(1) Grounded resistance near *R4* or *R5*
(2) *No. 1* motor grounded

With either defect the car will most probably refuse to move, as the current is led to ground before passing through the motors.

No. 1 motor may be tested by cutting it out of service by means of its cutout switch. If this removes the ground, the motor is at fault.

Fuse Blows near Last Point Multiple. In this case the cause is one of the following:

(1) *No. 2* motor grounded
(2) Either armature short-circuited

The fact that the fuse did not blow on the series positions excludes the resistances and *No. 1* motor from investigations for grounds. Cut out both motors. If the ground still exists, the controller is defective. If not, the fault may be located in either of the motors by cutting out first one and then the other.

Miscellaneous Tests

Armature Tests for Grounds. With a lamp bank at hand tests for grounded armature can be made as follows:

Throw the reverse on center. Attach one terminal of the lamp bank to the trolley. Put the other terminal on the commutator of the armature to be tested. If there is no current, the

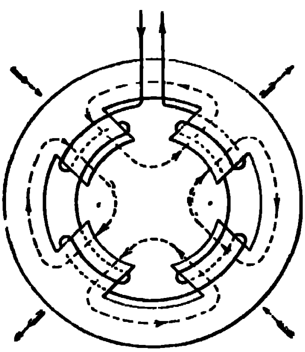


Fig. 150 Motor Field Coils Properly Wound

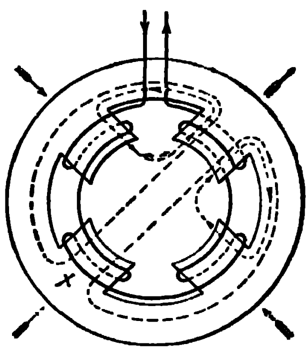


Fig. 151 Magnetic Field of Motor When One Field Coil Is Reversed

armature is not grounded; if current flows, remove the brushes and try again to be certain that the ground is not in the leads.

Field Tests for Grounds. Disconnect field leads and put the test point of the lamp bank on one side of the terminals. If no current flows, the fields are not grounded.

Reversed Fields. In placing new fields in the shell it often happens that one or more are wrongly connected. Reversed fields make themselves known by excessive sparking at the brushes.

In Fig. 150 all the fields are connected correctly. The flow of magnetism is into one pole and out of the adjacent one. Some of the magnetism leaks out of the shell and affects a compass held near the outside. The direction taken by the compass needle in the different positions is shown. The needle should point in opposite directions over adjacent coils and should lie parallel to the shell in positions halfway between two coils.

The flow of magnetism when one field is reversed is illustrated in Fig. 151. In such a case the compass will take the position shown. The field marked *X* is the one reversed.

With one reversed field a machine will usually operate, as the magnetism in three of the poles is in the normal direction. But an excessive flow of current that has no effect in turning the armature will take place on that side of the armature next to the reversed field.

Motor-Coil Testing. Testing for faults in the motor armature and field coils is done in a great variety of ways. The resistance of these coils can be measured by means of a Wheat-

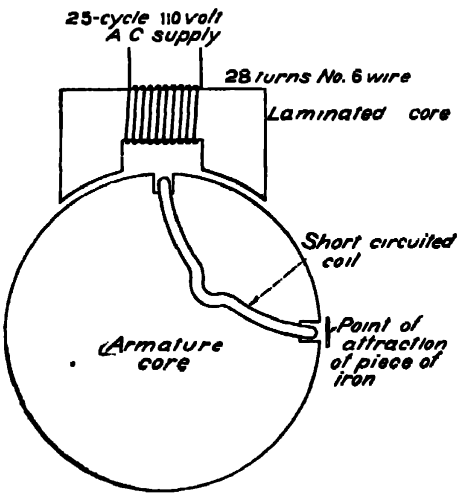


Fig. 152. Diagram Showing Transformer Test

stone bridge, employing a telephone receiver in place of the galvanometer used in such bridges in laboratory practice; but other less delicate tests are also in use.

Another method is to pass a known current through the coil to be tested and to measure the drop in the voltage between the terminals of the coil. The quotient of the voltage and the current is the resistance.

Transformer Test. A simple method, and one which involves no delicate instruments, is largely used in railway shop practice. This is known as the transformer test for short-circuited coils. It requires an alternating current, which can easily be supplied either

by the use of a regular motor-generator or by putting collecting rings on an ordinary d.c. motor and connecting these rings to bars of opposite polarity on the commutator. This method is indicated in diagram in Fig. 152. A core, built up of soft laminated iron, is wound with, say, twenty-eight turns of No. 6 copper wire. This coil is supplied with alternating current from a 110-volt circuit. The core has pole pieces made to fit the surface of the armature. When one side of a short-circuited coil in the armature is brought between the pole pieces of this testing transformer, the short-circuited armature coil becomes the short-circuited secondary of a transformer and a large current flows in it. This current will in time manifest itself by heating the coil; but it is not necessary to wait for this, as a piece of iron held over that side of the coil not enclosed between the pole pieces will be attracted to the face of the armature if held directly over the coil, but will be attracted at no other point. This testing can be done very rapidly and does not require delicate instruments or skilled operators.

Tests for short-circuits in field coils can be made in a similar manner by placing the coils on a core which is magnetized by alternating current. The presence of a short-circuit, even of one convolution of a field coil, will be apparent from the increase in the alternating current required to magnetize the core upon which the field coil is being tested.

Test of Insulation Resistance. The insulation resistance of armatures and fields is frequently tested by means of alternating current, about 2000 volts being the common testing voltage for 500-volt motor coils. One terminal of the testing circuit is connected to the frame of the motor, and the other to its windings. Any weak point in the insulation which cannot withstand 2000 volts will, of course, be broken down by this test. Alternating current is generally used for such tests because it is usually more easily obtained at the proper voltage, as it is a simple matter to put in an alternating transformer which will give any desired voltage and which can be controlled by a primary circuit of low voltage.

Open Circuits in Armature. Open circuits in the armature can be detected by placing the armature in a frame so that it

can be rotated, the frame being provided with brushes resting 90 degrees apart on the commutator. If either an alternating or direct current be passed through the armature by means of these brushes and the armature be rotated by hand, a flash will occur when the open-circuited coils pass under the brushes. A large current should be used.

Grounds. As one side of the circuit is grounded, any accidental leakage of current from the car wiring or the motors to ground will cause a partial short-circuit. Such a ground on a motor will manifest itself by blowing the fuse or opening the circuit-breaker whenever current is turned into the motor. In case the fuse blows when the trolley is placed on the wire and the controller is off, it is a sign that there is a ground somewhere in the car wiring outside the motors. Moisture and the abrasion of wires are the most common causes of grounds in car wiring. In motors defects are usually due to overheating and the charring of the insulation.

Burn-Outs. Burning out of motors is due to two general causes: (1) a ground on the motor, which, by causing a partial short-circuit, causes an excessive current to flow; (2) overloading the motor, which causes a gradual burning or carbonizing of the insulation until it finally breaks down.

Short-circuited field coils having a few of their turns short-circuited, if not promptly repaired, are likely to result in burned-out armatures, as the weakening of the field reduces the counter-e.m.f. of the motor, so that an abnormally large current flows through the armatures. Cars with partially short-circuited fields are likely to run above their proper speed, though, if only one motor on a four-motor equipment has defective fields, the motor armature is likely to burn out before the defect is noticed from the increase in speed.

Defects in Armature Windings. *Grounding.* Defects in armature winding cause a large part of the maintenance expense of electrical equipment of cars. Almost all repair shops have men continually employed in repairing them. The most frequent trouble with armatures is failure of the insulation of the coils and consequent grounding; this term is used in connection with armatures and fields and other electrical apparatus where a direct path

exists to ground. As the armature core is electrically connected to the ground through its bearings and the motor casing, a breakdown of the insulation of the coils in the slots permits the current to pass directly to ground. This shunts the current around the fields, and an abnormal current flows because of their weakness. The circuit-breaker or fuse is placed in circuit to protect the apparatus in such an emergency, but usually before such devices break the circuit, several of the coils of the armature are burned in such a manner as to make their removal necessary. The coils are so wound on top of one another that in order to replace one coil alone, one-fourth of the coils of the armature must be lifted.

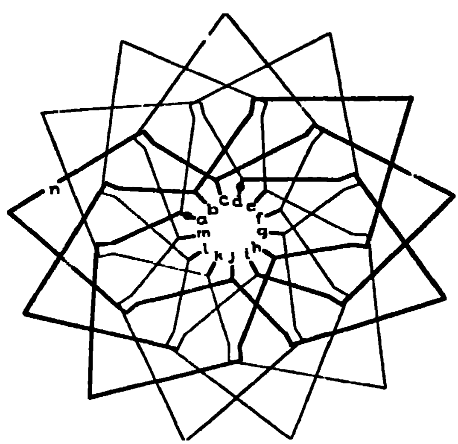


Fig. 153. Diagram Showing Effect of Open-Circuit in Armature Winding

With the armature of *No. 1* motor grounded the car will not operate, and if the resistance points be passed over, the fuse will usually blow. When *No. 2* motor is grounded, the action of *No. 1* motor is not impaired and it will pull the car until the controller is thrown to the multiple position. But if the motors are thrown in multiple, the path through the ground of *No. 2* motor shunts motor *No. 1*.

Open Circuits. Next to grounding, open circuits are the most serious defects of armatures. These are usually caused by burning in two of the wires in the slot or where they cross one another in passing to the commutator. Sometimes the connections where the leads are soldered to the commutator become loose.

The effect of an open circuit is shown in Fig. 153. The circuit is open at *n*. The brushes are on segments *a* and *d*. By tracing out the winding it will be found that no current flows through the wires marked in heavy lines. Whenever segments *c* and *d* are under a brush, the coil with the open circuit is bridged by the brush and current flows as in a normal armature. As

segment c passes out from under the brush, the open circuit interrupts the current in half the armature and a long flaming arc is drawn out.

In Fig. 154 is shown the result of a short-circuit between two coils. The short-circuit is at bc, the two leads coming in contact with each other when they cross. The effect is to short-circuit all the winding indicated by the heavy lines.

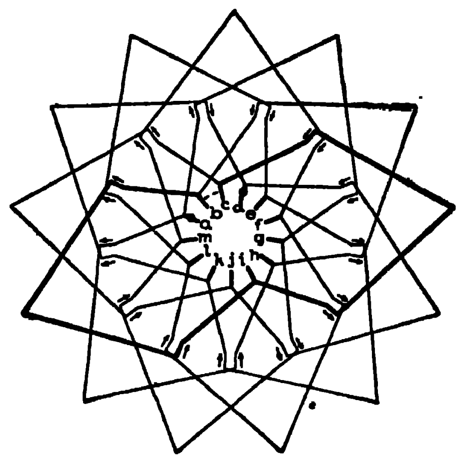


Fig. 154. Diagram Showing Effect of Short-Circuit Between Two Coils

Mistakes in Winding Armatures. The armature winder is given very simple rules as to winding the armature, but the great number of leads to be connected to their proper commutator segments sometimes so confuse him that misconnections are made. The effect of getting two leads crossed is shown in Fig. 155. The leads to segments b and c from the right are shown interchanged. This short-circuits the coils shown in heavy lines. The abnormal current resulting in these would usually cause them to burn out.

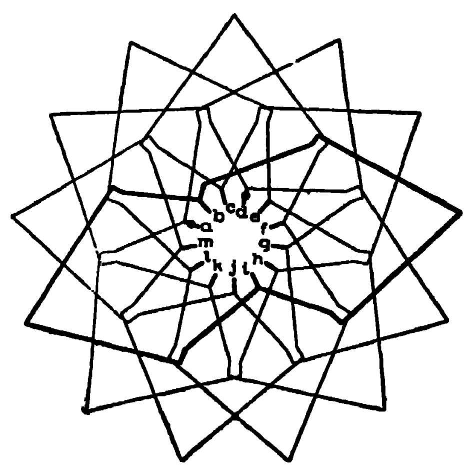


Fig. 155. Diagram Showing Effect of Crossed Leads

In Fig. 156 is shown the result of placing all the top leads or all the bottom leads one segment beyond the proper position. This causes the circuit starting from a and traveling counter-clockwise around the armature to return on segment m instead of on segment b as is the case in Fig. 154. The only result of such connections is to change the direction of rotation of the armature.

It may be noticed by comparing the two figures that with the positive brush on segments *a* the arrows show the currents to be in opposite directions in coils similarly located with reference to the position of the brushes. Some armatures are intended to be wound as in the last case mentioned.

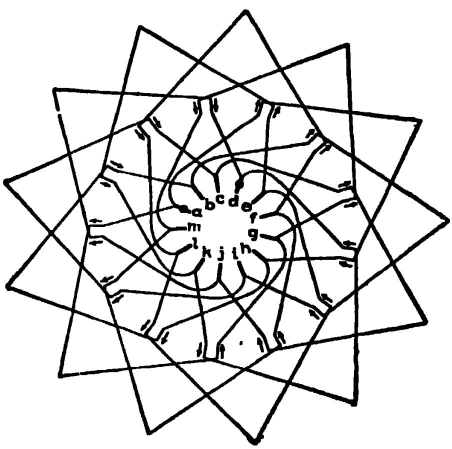


Fig. 156 Diagram Showing Effect of Wrong Connections to Commutator Bars

Sparking at Commutator. As railway motors are made to operate, and usually do operate, almost sparklessly, sparking at the brushes may be taken as a sign that something is radically wrong.

The pressure exerted by the spring in the brush holder may not hold the brush firmly against the commutator.

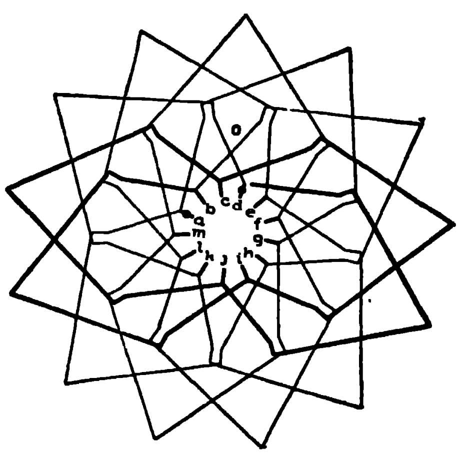


Fig. 157 Diagram Showing Effect of Open-Circuited Coil, Causing Sparking at Commutator

If brushes are burned or broken so that they do not make good contact on the commutator, they should be renewed or should be sandpapered to fit the commutator.

A dirty commutator will cause sparking.

A commutator having uneven surface will cause sparking and should be polished off or turned down.

Sometimes the mica segments between commutator bars do not wear as fast as the bars, and when this is the case, the brushes will be kept from making good contact when the commutator bars are slightly worn. The remedy is to take the armature into the

shop and groove out the mica between the commutator bars for a depth of about $\frac{1}{64}$ inch below the commutator surface. This grooving is found to be very beneficial also as a general practice; it greatly improves the whole operation of the commutator and brushes.

A greenish flash which appears to run around the commutator, accompanied by scoring or burning of the commutator at two points, indicates that there is an open-circuited coil at the points at which the scoring occurs, Fig. 157.

The magnetic field may be weakened by a short-circuit in the field coils, as before explained, and this may give rise to sparking.

Short-circuits in the armature may give rise to sparking but will also be made evident by the jerking motion of the car and the blowing out of the fuse.

Failure of Car to Start. The failure of the car to start when the controller is turned on may be due to any of the following causes:

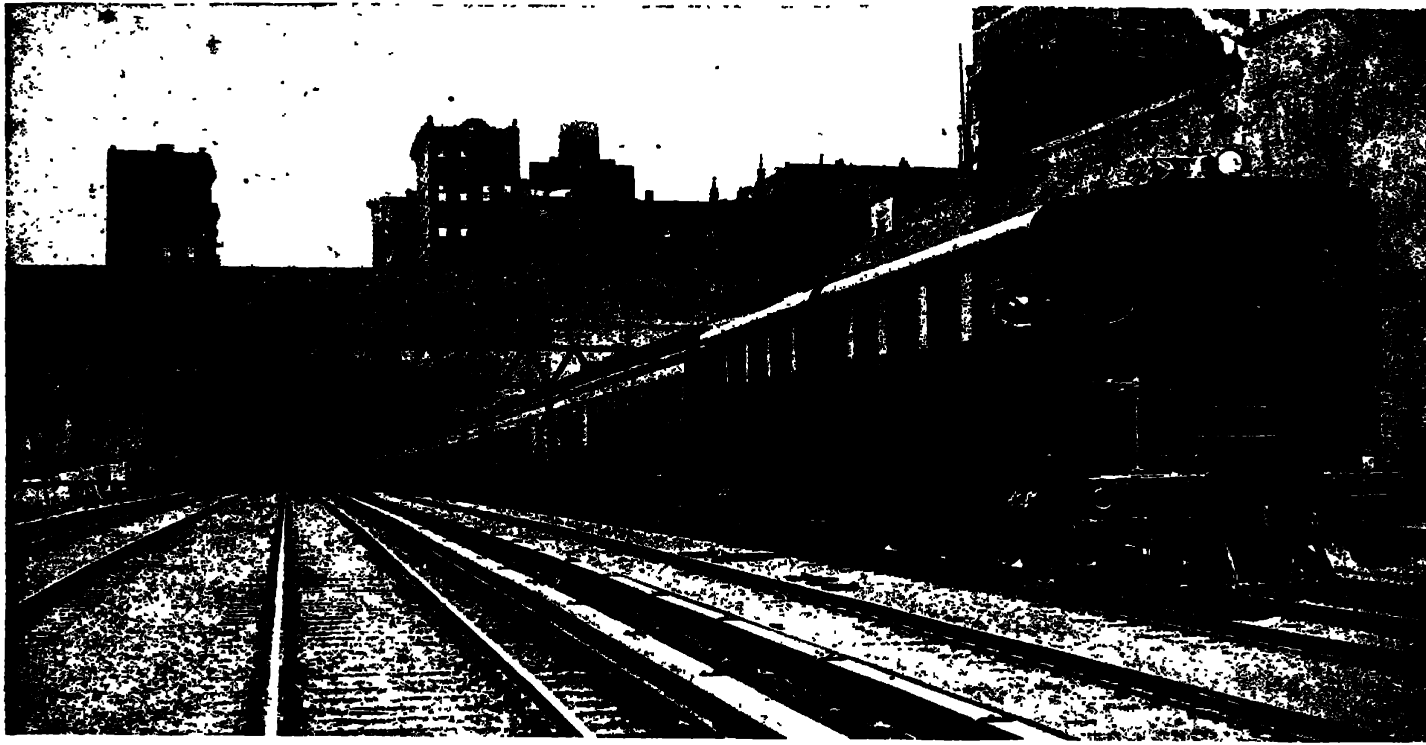
The circuit-breaker at the power house may have opened.

There may be poor contact between the wheels and the rails owing to dirt or to a breaking of the bond wire connections between the rails on which the car is standing and the adjacent track.

One controller may be defective in that one of the contact fingers may not make connections with the drum. In this case try the other controller if there is another one on the car.

The fuse may be blown or the circuit-breaker opened. The occurrence of either of these, however, is usually accompanied by a report which leaves little doubt as to the cause of the interruption in current.

The lamp circuit is always at hand for testing the presence of current on the trolley wire or third rail. If the lamps light when the lamp circuit is turned on, it is a tolerably sure sign that any defect is somewhere in the controllers, motors, or fuse boxes, although in case the cars are on a very dirty rail enough current might leak through the dirt to light the lamps, but not sufficient to operate the cars. In such a case the lamps will immediately go out as soon as the controller is turned on. Ice on the trolley wire or third rail will have the same effect as dirt on the tracks.



PENNSYLVANIA LOCOMOTIVE DRAWING HEAVY PULLMAN PASSENGER TRAIN OUT OF THE NEW YORK TERMINAL
Courtesy of Westinghouse Electric and Manufacturing Company

ELECTRIC RAILWAYS

PART III

POWER PLANTS

Characteristic Features. From his study of electric generators earlier in the course the student is familiar with the general principles of the electrical machinery of power stations, and of switchboards, and of electrical auxiliaries. With this foundation it will be easy to study the characteristic features of railway power stations. These stations owe their distinguishing features to the following facts:

(1) The load is of a fluctuating character.

(2) As a rule, the power must be generated in a form suitable for transmission to fairly long distances because a railway usually covers a large territory.

(3) The power supply must be very reliable.

Fluctuating Load. The railway load is of a fluctuating character, *first,* because each car takes current irregularly; and *second,* because the number of cars operated at one time is quite variable.

The momentary fluctuations are especially notable in a road having but few cars. Here the starting or stopping of each car results in a peak or a depression in the load curve of considerable magnitude in proportion to the average load. A load diagram from such a road is shown in Fig. 158.

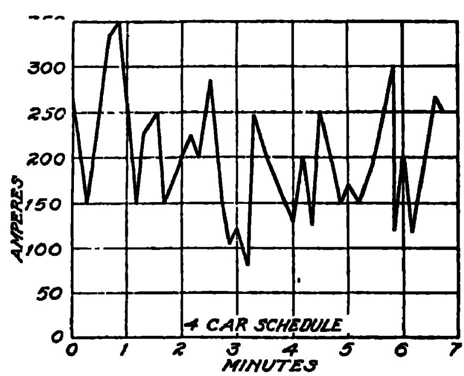


Fig. 158. Load Diagram for Small System

In large roads the momentary fluctuations do not amount to much because each car draws a smaller proportional amount of power and the starting currents are not so noticeable. In this case, however, the fluctuations during the whole day are greater

because the number of cars in operation varies more than in the small road, which is apt to have a rather uniform schedule. In the large road it would not pay to run the same number of cars

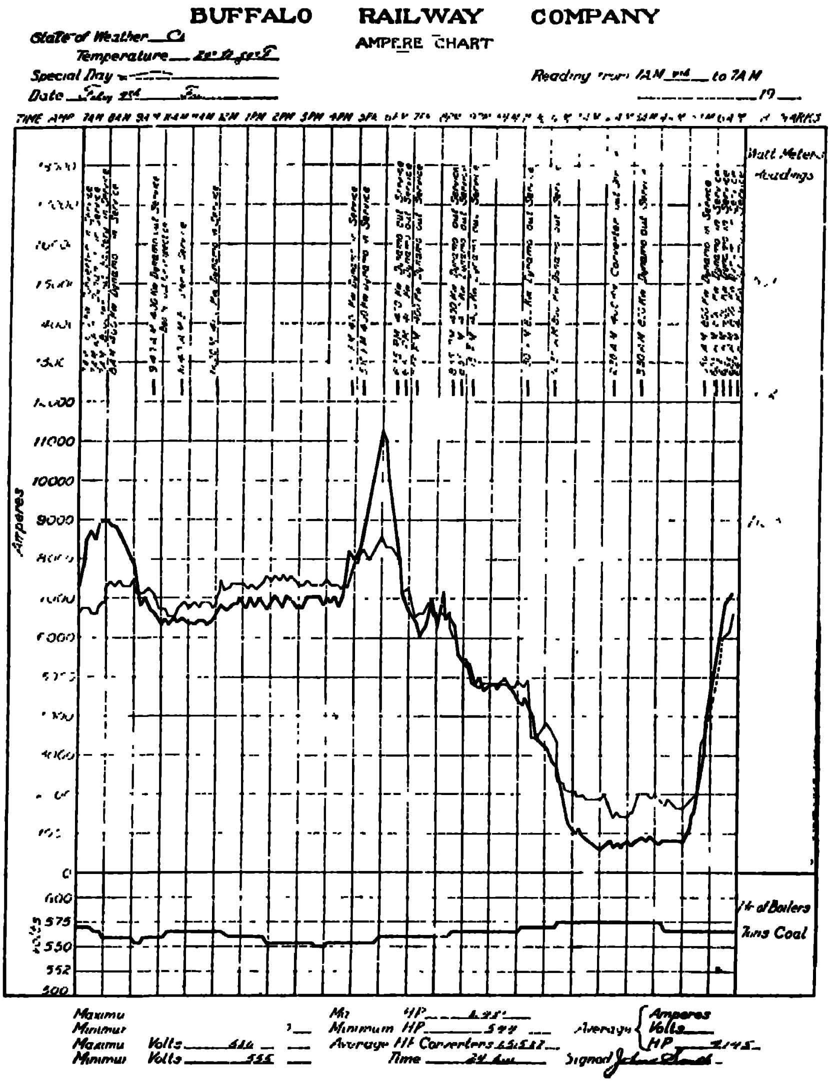


Fig. 159. Load Diagram for Large System

at 10 A.M. as at 6 P.M., for most of them would be empty. A typical diagram for a large system is given in Fig. 159, in which the heavy line is the amperes to line and the light line the

amperes from generators. The difference is due to the storage battery; when the heavy line is above, the battery is discharging, and vice versa.

Economic Requirements. As a power house is an electrical energy factory, it is subject to the same economic laws as any other factory. Its function is to produce reliable electrical energy at a minimum total cost per kilowatt hour. To operate economically requires that boilers, engines, generators, etc., be allowed to furnish an output as near their full-load capacity as possible in order that the efficiency may be high. In studying the layout of a few typical stations the foregoing points should be kept in mind to see how the requirements are met in practice.

POWER HOUSE CONSTRUCTION AND ARRANGEMENT

Raw Materials. In a power plant the principal raw materials are fuel, air, and water. It is a good plan to follow the routes of these through the plant in regular order and thus eliminate the danger of overlooking any important feature.

Coal Circuit. The coal circuit begins with the coal pocket or storage. This coal is conveyed in one way or another to the boiler room. It is fed to the boilers either automatically or by hand. The ashes leave the grates and are handled either automatically, semi-automatically, or by hand, and finally they are delivered outside the building.

The air for the combustion of the fuel is drawn in from the boiler room, or it is supplied by fans under pressure. It passes through the fire bed and is sucked away from the fire by the chimney or stack or by suction fans. On the way to the chimney it may pass through an economizer and give up some of its heat to the feed water, which circulates through the economizer in pipes.

Feed Water. The feed water comes, in the first place, from the source of water supply. It passes through pumps in most plants, although injectors may be used if the water is not too hot. In general, the feed water is heated by passing it through atmospheric heaters into which the steam discharges from the noncondensing engines and pumps. This heater can be arranged as a purifier also if the water is allowed to flow slowly over pans. Scale precipitates under the action of heat in this way, and it is

prevented from forming in the boiler. Another plan for preventing the formation of boiler scale from the feed water is to add chemicals which will prevent the precipitation of the scale under the action of heat.

In very large plants a heater is sometimes used in the exhaust-steam circuit from engine to condenser as explained later, but in general this is an unnecessary refinement. In some plants the feed water then goes through the economizer where it is heated to a high temperature, say 212° F., by the flue gases. It then flows into the boiler.

Steam Circuit. The steam circuit begins at the boiler where steam is generated in a saturated condition. It may be superheated either by tubes above the water line in the boiler or by a separately fired superheater. After flowing through the risers, headers, and leads it passes to the engines—through steam separators if there is any danger of condensation in the piping. It is practically necessary that the engines get dry steam. From the engines the steam goes to the condenser or to the atmosphere, the latter being an extremely wasteful process. The condensing chamber is kept cool by the circulation of cool water through pipes so that the steam is immediately condensed. In some plants there is a vacuum feed-water heater between the engine and the condenser. Such a heater relieves the condenser by partly performing its function. It also heats the feed water slightly and thus helps the atmospheric heater. The condensed water then goes to the hot well for use in the boilers again. If jet condensers are used, the condensed steam and condensing water are mixed and there is but a small portion of the water used again. Jet condensers, while simple in construction, can only be used where the water is reasonably pure.

Circulating Water. The circulating water for the condensers comes from a stream or from a reservoir in connection with a cooling tower. It is pumped through the condenser either by a pump or by its own weight (as in the barometric type); after this it flows out again, being either wasted or returned to the cooling tower to give up its acquired heat. If jet condensers are used, the water is partly returned to the hot well for boiler feed and partly returned to the source of supply, as before.

Power Circuit. The power circuit begins at the engine where mechanical power is transformed into electrical power. From the generator the power flows through the electrical circuit to the switchboard, thence to the transformers, if any are used, and it finally reaches the outside circuit. Before doing so, it may be converted from one form to another, as, for example, from three-phase alternating current to direct current for railway purposes.

Available Percentage of Energy of Coal. The process of converting the energy of coal into electrical energy is an extremely inefficient one, even with the most improved machinery. In Fig. 160 is shown an approximate division of the losses from the coal pile to the motors of the trolley car. In this diagram it will be seen that only slightly more than one-half of the energy in the coal is actually delivered to the engine, while additional losses in auxiliaries and condensing water bring the energy available for mechanical work down to about 11 per cent. There remains to be accounted for the average all-day loss in electrical apparatus, including generators, transformers, transmission line, substations, feeder and track, and, lastly, in the cars themselves, which ordinarily deliver to the rim of the driving wheels from 50° to 60 per cent of the energy measured at the power-station switchboard. The approximate figures used represent average conditions and can be improved upon by careful operating supervision. In some large plants with steam turbines operating under ideal conditions as much as 15 per cent of the energy of the coal appears at the shaft of the engine.

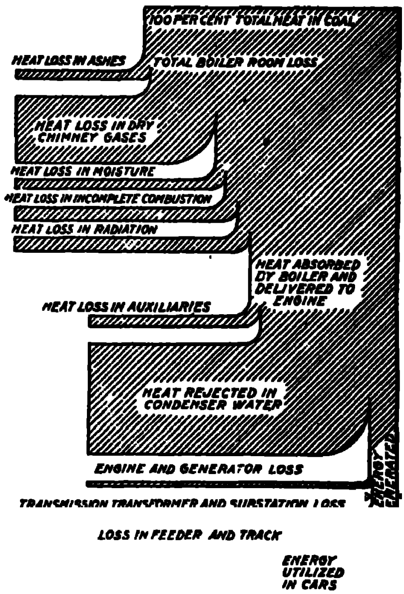


Fig. 160. Diagram Showing How a Large Percentage of Heat Is Dissipated

Heating Value of Coal. The amount of heat in coal is defined in heat units per pound, or British thermal units. The

B.t.u. is defined as the amount of heat required to raise the temperature of 1 pound of pure water from 62° to 63° F. The heating value of coal varies from 10,200 B.t.u. to as high as 15,800 B.t.u., and it is necessary for large users to take this value into account when purchasing power house fuel. Many large electric power stations stipulate in their contracts that coal shall have a certain heating value, the actual price paid being based on the results of chemical analyses.

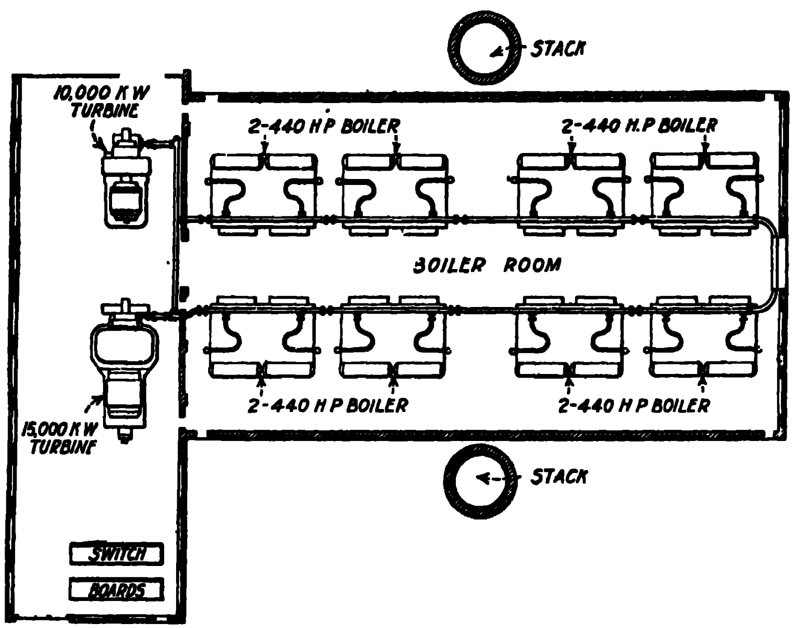


Fig. 161. Steam-Turbine Power Station

Typical Electric-Railway Power Plant. The principal elements of a modern electric power station are shown in Figs. 161 and 162. The building is of fireproof construction, a fireproof wall separating the boiler room from the turbine room. The steam main passes through the wall to a steam header, from which steam is piped to the turbines. Where other load is available, it is good practice for a railway plant to take on industrial load in order to secure a more uniform load factor. The station shown was built by the Columbus Railway Power and Light Company to supply light and power as well as city and interurban railways. The railway plant generates three-phase current, either 25 or 60

cycles, and transmits to substations containing synchronous converters or motor-generator sets for transforming the alternating current to direct current.

Boiler Room. Beginning at the right of Fig. 161, it will be noted that the main part of the station is occupied by sixteen 440-hp. boilers set in batteries of two each. These boilers are designed for 250 pounds pressure and are provided with superheaters capable of producing 150 degrees of superheat. Coal is brought in on a spur track and is carried by a conveyor to a crusher and

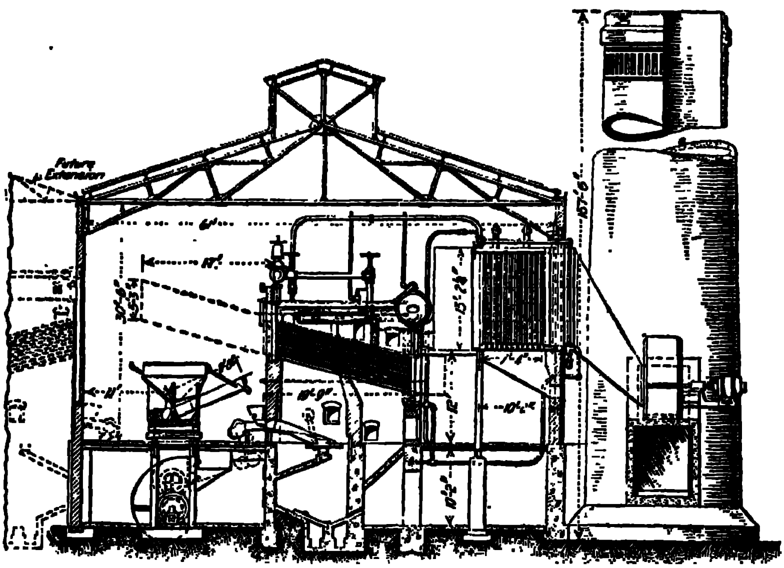


Fig. 162. Elevation of Boiler Room

then to the two 400-ton coal bunkers just outside the boiler room. An electrically operated 4½-ton lorry operates between the coal bins and the boiler room, supplying the underfeed stokers on either side of the aisle. The gases pass out through economizers in which the feed water circulates. The ashes from the boilers drop into a pit formed by the concrete foundations. In this pit are two drag-chain conveyors for each row of boilers, carrying the ashes to mechanical car-loading apparatus.

The feed water passes from the economizer to a header and thence to the boilers. The water pumps are motor driven. In the

aisle between the boilers will be noted the motor-driven fans for driving the flue gases into the 150-foot chimneys.

Turbine Room. Steam passes to the turbine room through a 12-inch main header for each row of eight boilers. Two turbo-generator sets are installed, one of 10,000 and the other of 15,000 kilowatts capacity. The turbines are of the Curtis or impulse type, and the generators deliver three-phase 60-cycle current at 13,200 volts. A surface condenser is located below each turbine unit, maintaining a vacuum on the discharge side of the turbine. Each turbine carries a direct-connected exciter, and an additional 100-kilowatt turbine-driven exciter unit is provided as a spare.

Transmission. For transmission over three of the outgoing transmission lines the voltage is raised to 39,400 volts, while a fourth line takes power at the generator voltage. The transformers are each of 15,000 kilovolt-amperes and are three phase and water cooled, space being provided for three units. As a matter of economy these are of the outdoor type, as are also the oil circuit-breakers and aluminum-cell lightning arrester.

Modern Tendencies. A good idea of the trend of power-station development is shown by the new Windsor plant of the West Penn Power Company. This development is located in West Virginia about 2000 feet from a coal mine producing fuel with a heat value of about 13,500 B.t.u. per pound. Power is used to operate more than 400 cars over 322 miles of the West Penn Railways besides industrial and lighting load. A diversified load is thus secured, which improves the efficiency of the plant.

The unit plan is used with four boilers and one 30,000-kilowatt turbo-generator per unit. Four units are operating, and two more are under construction, making a total of 180,000 kilowatts, which gives an idea of the tendency toward large units.

This plant has a number of special features due to local conditions, which may be noted in Figs. 163 and 164. The generator voltage is 11,000 volts, 60 cycle, three phase, and power is transmitted both at 130,000 and 66,000 volts. One of the unusual features is the outdoor switching and transformers.

The prevailing tendency is now toward the purchase of power for electric-railway operation from a large power-producing station. These plants, making electricity in quantity, can sell in large

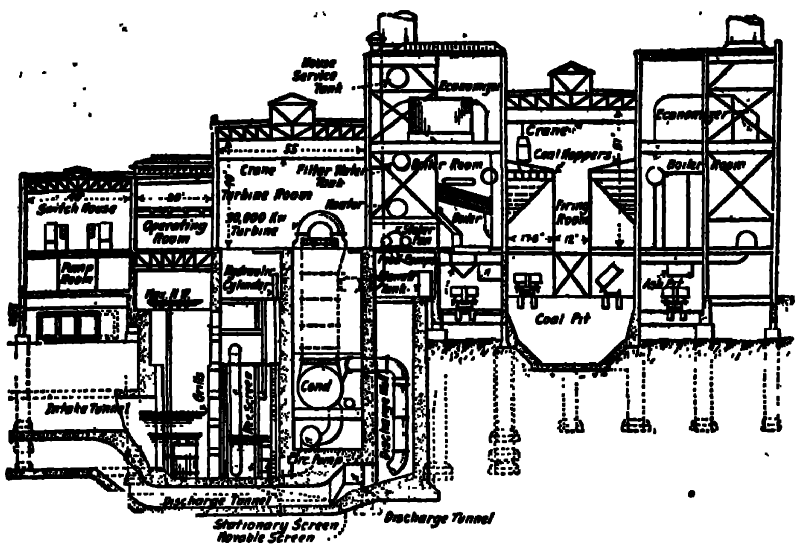


Fig. 163. Cross-Section through Windsor Plant

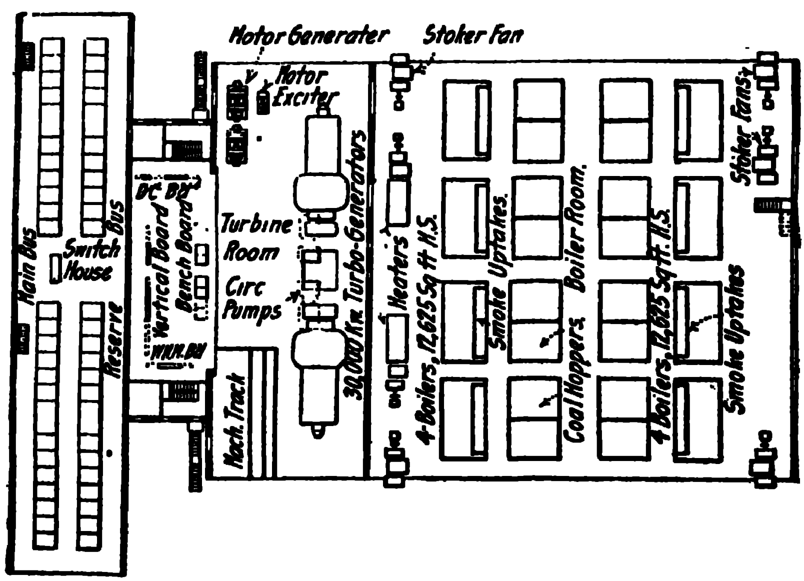


Fig. 164. Simplified Plan of Windsor Plant

amounts at a low figure and thus relieve the railway company of the investment and operating expense of an independent plant. This practice is well illustrated by the Butte, Anaconda and Pacific Railway and the Chicago, Milwaukee and St. Paul Railway electrifications, where hydroelectric power is purchased at 0.536 cent per kilowatt hour. Another recent electrification is the Paoli division of the Pennsylvania Railroad, and all the power is bought from the Philadelphia Electric Company.

ELECTRICAL DETAILS OF POWER PLANTS

Direct Current Generation. *Extent of Use.* The student may gather from the first part of this discussion of power plants that the d.c. generator has been entirely superseded by the a.c. generator and the synchronous converter. In general, this arrangement is followed in most railway systems; however, in some special cases it is desirable to generate direct current and feed to the trolley without transformation. This is the scheme originally employed by electric-railway systems when using slow-speed reciprocating engines and direct-connected generators. The high cost of slow-speed apparatus, however, has forced electric-railway operators to make use of the a.c.-d.c. arrangement described.

In some cases where the length of feed is short, so that one substation is sufficient to supply the entire trolley system, a single generating plant can be used supplying direct current at either 600, 1200, or 1500 volts. The generating unit in this case would be preferably a steam turbine direct connected through a reduction gear to the d.c. generator. Where a 1500-volt current is used on the trolley, a generating station of this type can supply cars for a distance of about ten or fifteen miles in each direction. The objection to an installation of this kind, however, is that in case of an extension, such as a new interurban line, it is necessary to resort to higher voltage for transmission. In other words, the a.c.-d.c. system is adapted to indefinite extension, while the straight d.c. generation is limited as to the area it can supply.

Equipment. Direct-current plants are usually equipped with compound-wound generators designed to deliver normal voltage from no-load to somewhat higher than full-load capacity. Where two or more machines are operated in parallel, it is necessary to

use an equalizer bus connecting the points between the armature and the series field of each machine. This connection ensures an equitable division of the load current between the series fields and thus maintains uniform load on all the machines operating in parallel. Fig. 165 will enable the student to trace out the division of load between the two machines.

Connecting in Second Generator. In starting up a compound-wound generator to be operated in parallel with one already running, the new machine is first brought up to speed. The switch controlling the shunt field is then closed, causing the generator voltage to build up. When this potential is practically equal to the bus-bar voltage, the operator closes the positive switch,

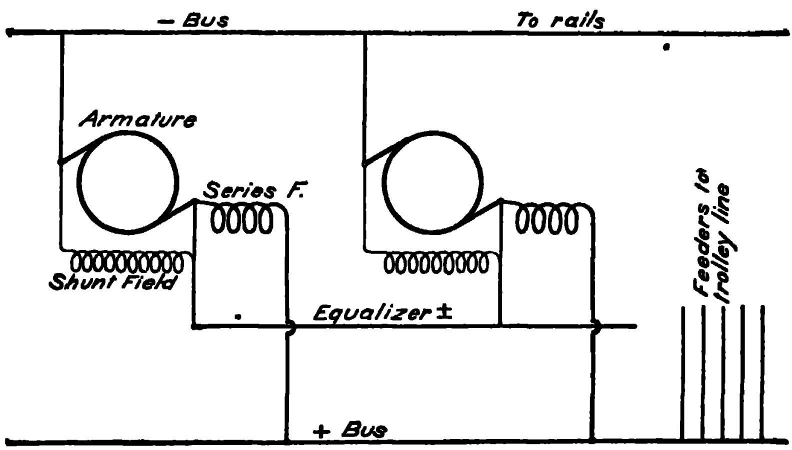


Fig. 165. Diagram of Connections for Direct-Current Power Plants

assuming that the equalizer switch on the generator has already been closed. This connects the series field of the new generator in parallel with the series fields of the machines already running. The voltages on the new machine and on the bus are then tried alternately until they are as nearly equal as possible. An accurate comparison can be made by the use of a voltmeter plug which connects the same voltmeter either to the bus bars or to the new generator. After correct adjustment is secured, the negative switch of the new generator is closed, connecting the machine to the station bus. If the new generator does not take its proper share of load, further adjustment can be made by the shunt-field switch, forcing the generator to take its share of load as

shown by the ammeters by increasing or decreasing the strength of the shunt field.

Direct-Current Power-Station Switchboards. The panels used in a d.c. railway power-station switchboard are of two kinds, the generator panels and the feeder panels. These are quite similar to those used for railway substation work and will be described under the heading Substations.

Alternating-Current Power-Station Switchboards. On railway systems where alternating current is used for generation and trans-

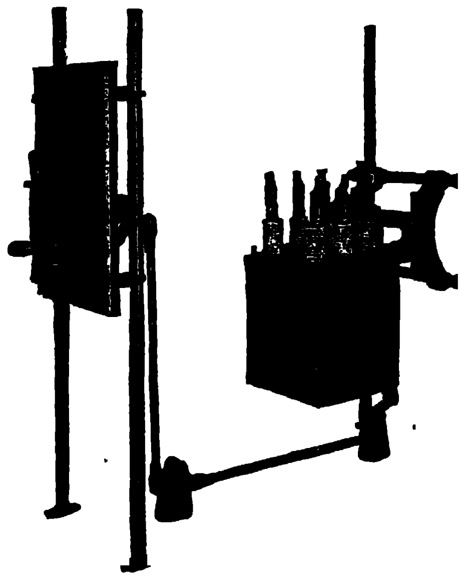


Fig. 166. Three-Phase 500-Ampere Oil Switch Remote Controlled and Mounted on Pipe Framework
Courtesy of General Electric Company, Schenectady, New York

mission it is necessary to provide switchboards capable of handling high-tension current at whatever may be the transmission or station voltage. The a.c. switchboard differs from the d.c. switchboard in that the switches proper are not brought out to the front of the panel. They may be located either directly back of the panel, above or below in fireproof enclosures, or at some distance from the operating board.

Alternating-current circuits at moderate and high voltages are ordinarily broken under oil by means of what is called an oil

circuit-breaker. The switch contacts are immersed in a tank of oil, and the conductors are brought out through insulating bushings, Fig. 166. The tank may be lowered for inspection or repairs, as shown in the illustration. Two types of remote-control switches are used, one being operated by means of a system of rods and bell cranks, while the other is controlled by means of an electrical circuit operating a solenoid or motor mechanism which performs the actual opening and closing of the switch. Usually the breaker opens by gravity assisted by compression springs on the operating rods. When the breaker is released, the springs assist in opening the breaker at a higher rate of speed than would be obtained by gravity alone. The construction varies with the amount of current to be interrupted, the voltage of the circuit, and also the amount of synchronous apparatus connected to the system of which the station is a part. It is necessary to take this factor into consideration, since under short-circuit conditions all the synchronous apparatus for a very short period will tend to pump current into the short-circuit as a result of the inertia of the moving parts. The oil circuit-breaker must therefore be capable of handling the current to be interrupted under these conditions.

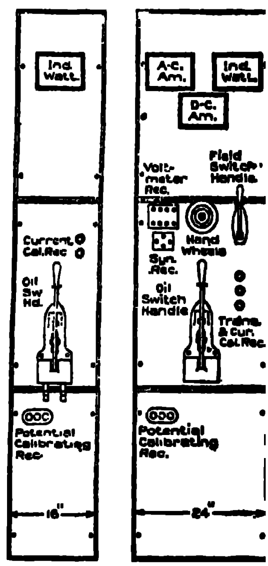


Fig. 167. Alternating-Current Switchboard

Types. In Fig. 167 is shown a diagrammatic view of an a.c. switchboard designed for 2300 volts, three phase, and the switches are operated from the front of the panel by means of bell cranks and connecting rods. In Fig. 168 is illustrated a board with two generator panels and one feeder panel; the live parts are enclosed as a safety measure. A view in the transformer room of one of the Chicago, Milwaukee and St. Paul Railway substations is given in Fig. 169. The transmission voltage in this case is 100,000, and the oil switches are constructed with each pole in a separate tank. The apparatus is operated by means of a solenoid actuated from a small control switch on the main switchboard. Certain types of

switch of large current-interrupting capacity and moderately low voltage, for example, 15,000 to 33,000 volts, employ circuit-breakers having each unit enclosed in a separate brick or concrete cell and operated by a small motor located above the cell, Fig. 170. In this case the switch is closed by the motor against a heavy compression spring and opened by tripping a trigger which is set when the switch is closed. The switch thus opens at high speed, owing to the force of the spring, and the arc is broken in the oil

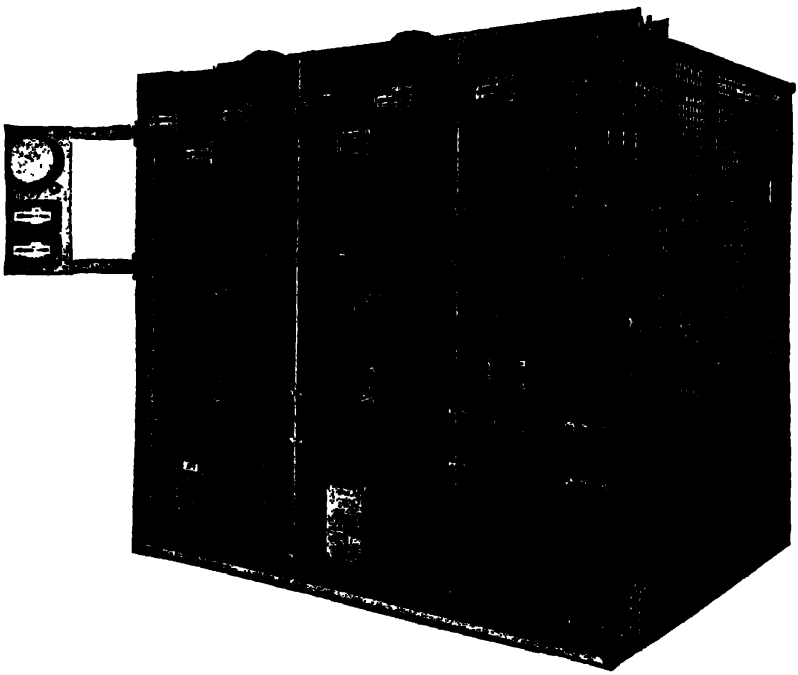


Fig. 168. Switchboard Panels for Three-Phase 3500-Volt Current
Courtesy of General Electric Company, Schenectady, New York

surrounding the contacts. Circuit-breakers of this character are shown in Figs. 171 and 172. The type of switchboard unit shown in Fig. 173 is designed with the instrument and switching equipment mounted on a truck which is wheeled into a cubical compartment containing permanently the busses and cable terminals. An interlocking device prevents the removal of the truck except when the oil switch is open.

Circuit-Breakers. *Oil Type.* Automatic current-interrupting devices for d.c. circuits are termed air circuit-breakers to dis-

tinguish them from oil circuit-breakers, which are used for a.c. circuits. The oil circuit-breaker is not suited to d.c. service, since the direction of current flow does not reverse and an arc once set

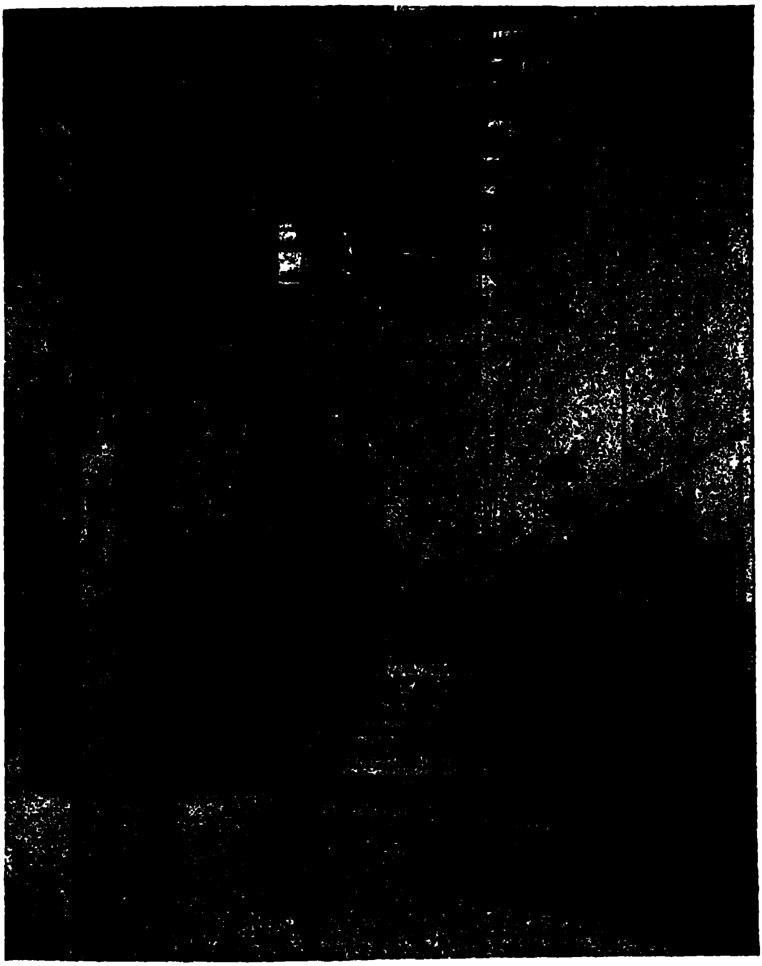


Fig. 169. 100,000-Volt Oil Switches, Piedmont Substation, Chicago, Milwaukee and St. Paul Railway Electrification
Courtesy of General Electric Company, Schenectady, New York

up through the oil tends to maintain its path by carbonizing some of the oil. With alternating current, however, the oil surrounding the switch terminals tends to interrupt the arc at the moment of reversal when the current reaches a zero value.

Air Type. The air circuit-breaker, Figs. 174 and 175, usually consists of a laminated copper-brush bridge which is pressed against two copper terminal blocks by a toggle joint operated by a handle. These breakers contain a core magnetized by the main current, which acts upon an armature suspended just below the

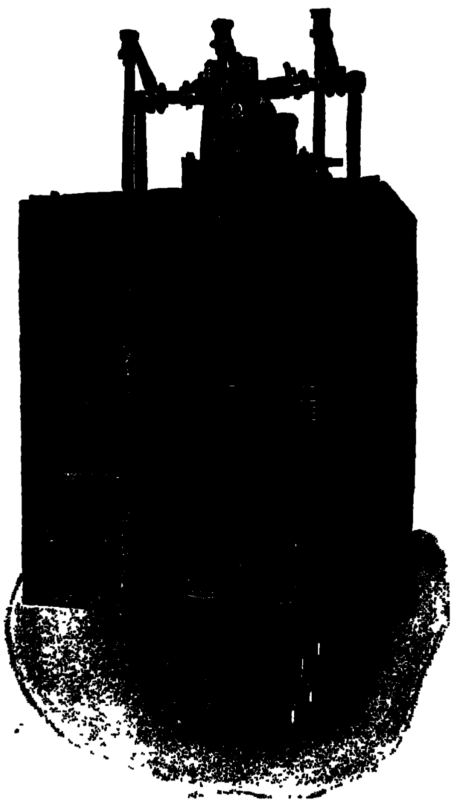


Fig. 170. 15,000-Volt, 1200 Ampere Oil Circuit-Breaker Using Motor-Operated Mechanism

Courtesy of General Electric Company, Schenectady, New York

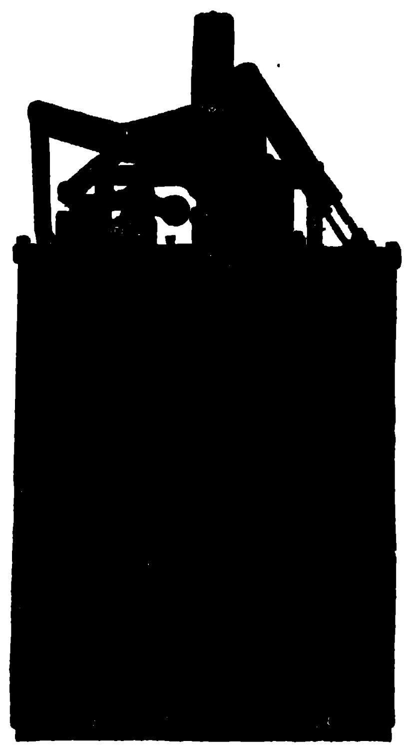


Fig. 171 3000-Ampere Three-Phase Electrically Operated Oil Circuit-Breaker at Right, Pole Enclosed; at Center, Door Removed and Tank in Place; at Left, Door and Tank Removed

core. When the current rises above a certain predetermined amount, the armature is drawn up, tripping out the main contacts, which fly open under pressure of the heavy spring. Upon the opening of the main contacts the current is transferred for an instant to the auxiliary contacts, they being fitted with carbon tips which are not so easily burned and can be readily replaced. In

some types a magnetic blow-out is used to assist in interrupting the current. In addition to the overload trip, a shunt or no-voltage trip coil can be used. The main brush contacts are constructed so that a wiping or rubbing action takes place between the copper block and the brush, thus ensuring a clean contact surface.

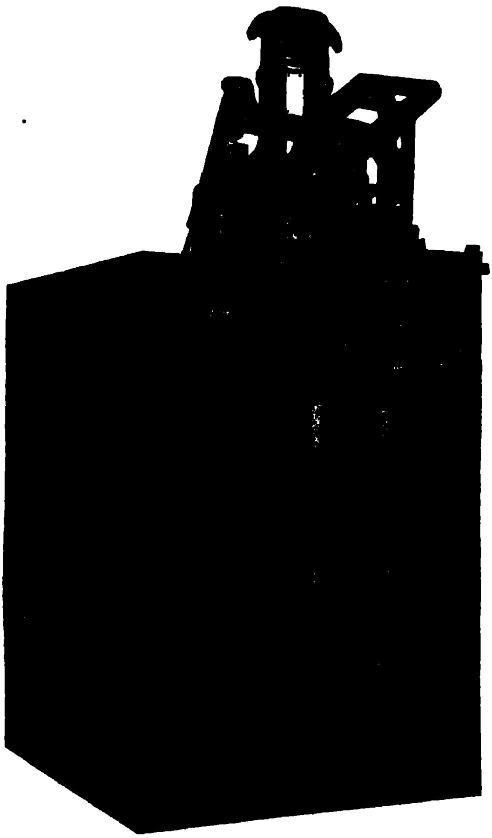


Fig. 172. Side View of Fig. 171, Showing Contact Mechanism

Oxide-Film Arrester. An important development in lightning arrester construction is the oxide-film type, which has all the advantages of the aluminum-cell type; in addition, it has no liquid to freeze during cold weather and requires no charging, which is necessary in the aluminum-cell type.

Each cell, Fig. 176, of this arrester consists of two sheet-metal disc electrodes held about $\frac{1}{2}$ inch apart by a porcelain ring. A

thin insulating film of varnish or shellac covers one or both discs, and the space between the plates is filled with peroxide of lead.

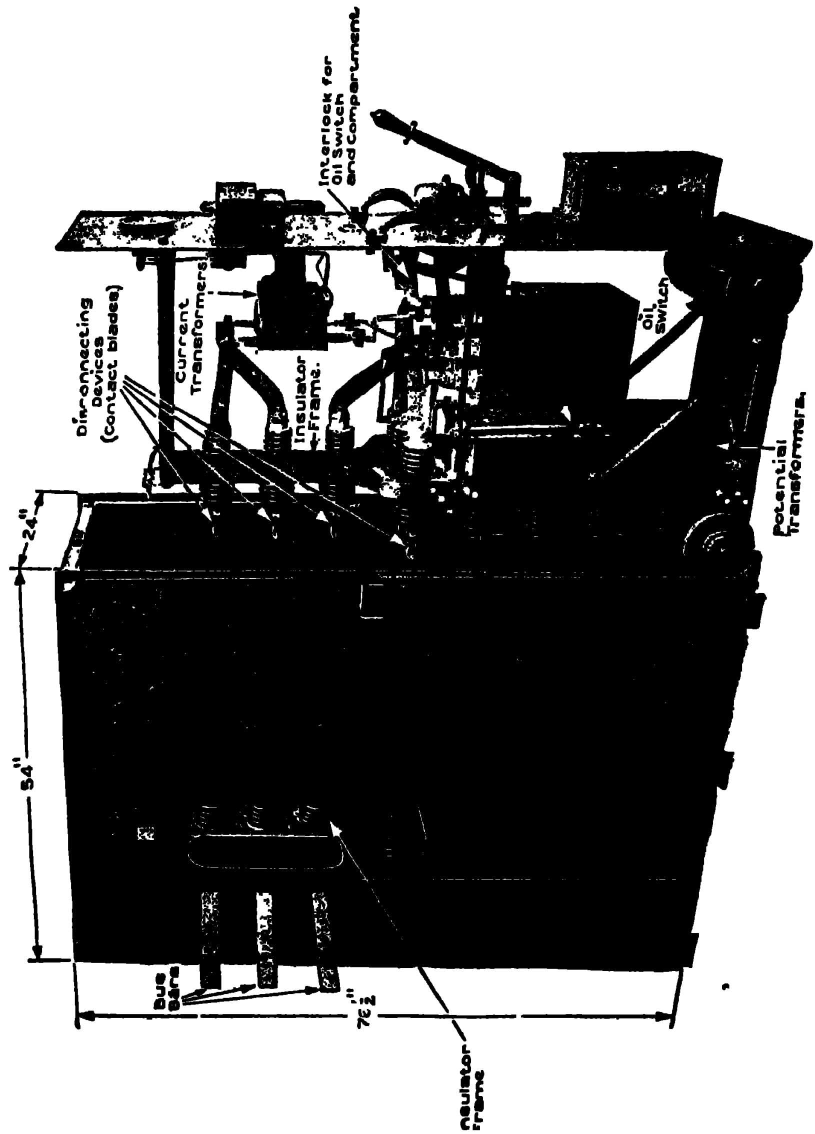


Fig. 173. Truck Type Switchboard Panel Unit for Three-Phase Station

The metal discs are spun over the edge of the porcelain, making a hermetic seal. At the permissible voltage per cell, 300 volts a.c

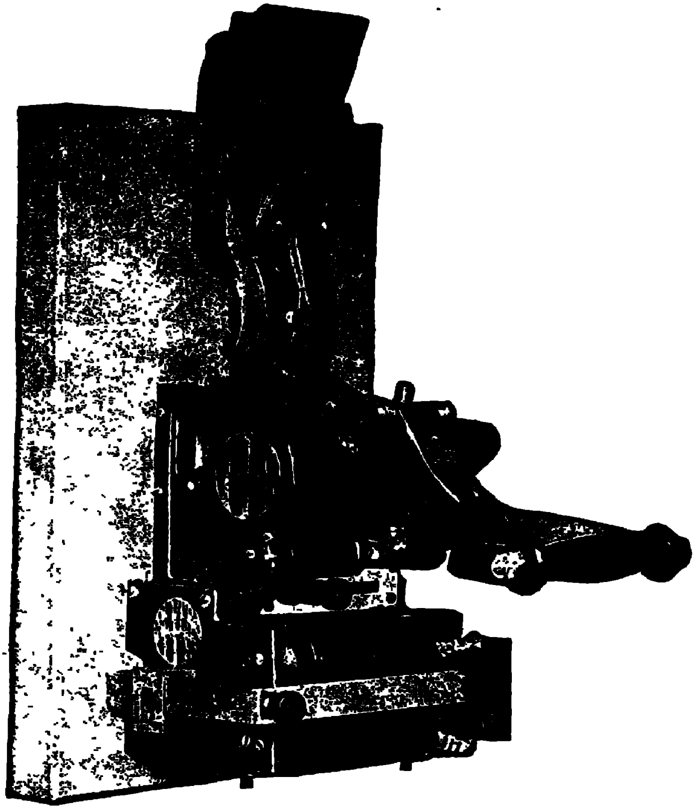


Fig. 174. I-T-E Circuit-Breaker

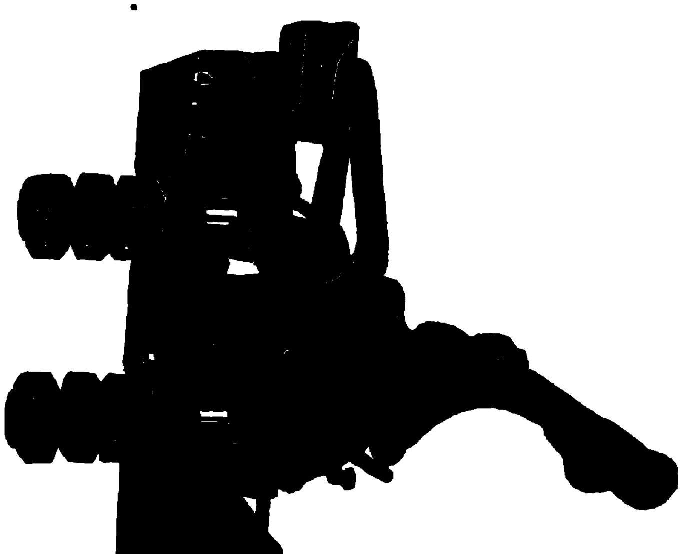


Fig. 175. General Electric Circuit-Breaker, Showing Method of Mounting

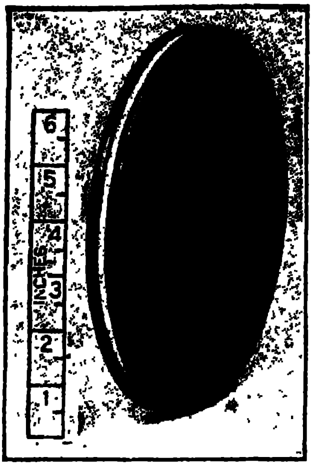


Fig. 176. Single Unit of Oxide-Film Lightning Arrester
Courtesy of General Electric Company, Schenectady, New York

or 600 volts d.c., the insulating film prevents any appreciable flow of current, but when the voltage rises slightly above normal, the film punctures and a lightning discharge meets practically no resistance in its flow to ground. When dynamic current starts to flow, the rise in temperature causes the film to reseal, this action taking place in less than $\frac{1}{1000}$ second. One or more cells are used in series, depending on the voltage of the system.

From Fig. 177 it will be noted that the arrester is protected by a horn gap, across which the overvoltage must pass to reach the arrester.

Fig. 177. Lightning Arrester Protected with Horn Gap
Courtesy of General Electric Company, Schenectady, New York

SUBSTATIONS

Function. The a.c. three-phase power generated in the mair power house or purchased from commercial power plants is distributed by means of high-tension transmission lines or high-tension underground cable systems to substations located at suitable points for distributing power in d.c. form.

Spacing. On 600-volt systems the substations may be locatec in some cases as far as 10 miles apart for ordinary interurban service. For city service it is more economical to place the stations near together, thus avoiding some of the heavy distribution losses. On 1200-volt interurban roads stations may be placed approximately 15 miles apart for light service. When 3000-volt direct current is used, as in the case of the Chicago, Milwaukee and St. Paul Railway, the spacing of the substations may be as high as 30 miles. The number of substations on a railway system and the capacity of each depend, of course, upon the extent of the system and the amount of traffic handled, both freight and passenger. The station is made as small as possible for housing the necessary equipment, but it is customary to make provision for additional units in case of increased load requirements.

Equipment. The transmission-line voltage is stepped down, by means of transformers, to the a.c. voltage required by the synchronous converters or motor-generator sets, as the case may be. The substation usually includes, besides transformers and converting apparatus, the necessary a.c. and d.c. switchboards, lightning arresters, and conveniences for the operators. In some cases it is considered advisable to use storage batteries to provide emergency power supply and also to secure a more uniform load.

The arrangement of apparatus in a typical substation containing two 500-kilowatt converters is illustrated in Figs. 178 and 179. Referring to Fig. 179, the incoming line enters the substation through the roof on the left side at 11,000 volts and passes through oil circuit-breakers, choke coils, etc., to two banks of three single-phase transformers, one bank for each converter. The ratio of transformation is 11,000 to 430 volts, which is the correct alternating current to deliver 600 volts at the d.c. commutator. As may be seen in Fig. 178, a lightning arrester is connected to

the 11,000-volt bus through a horn gap which is ordinarily left open. Provision is made for short-circuiting the horn gap

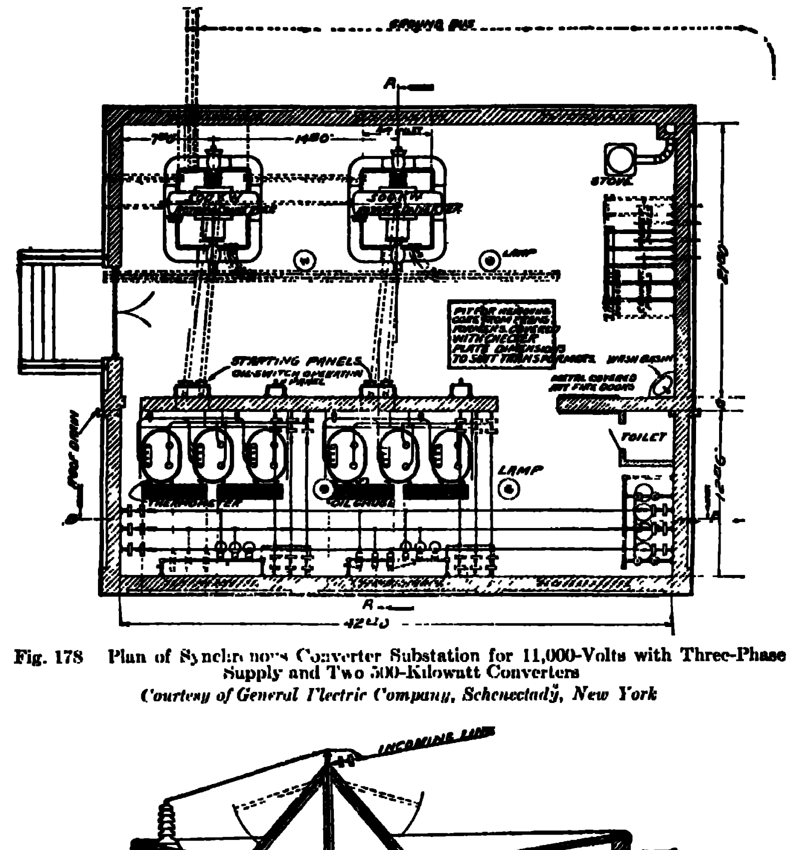


Fig. 178 Plan of Synchronous Converter Substation for 11,000-Volts with Three-Phase Supply and Two 500-Kilowatt Converters
Courtesy of General Electric Company, Schenectady, New York

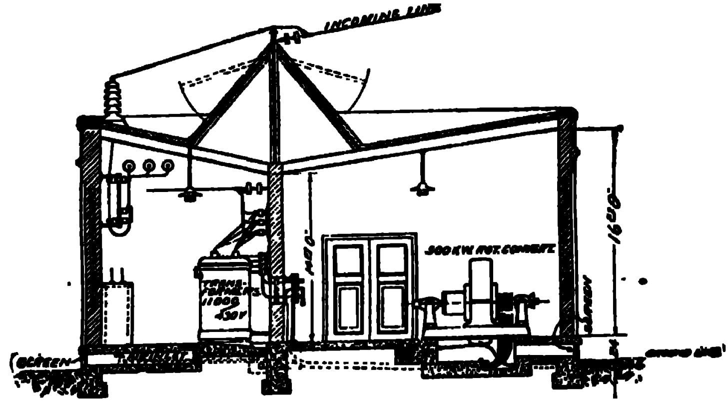


Fig. 179. Section A-A of Fig. 178 Showing Converter, Transformer, and Lightning Arrester
Courtesy of General Electric Company, Schenectady, New York

and thus charging the lightning arrester at stated intervals. The choke coils between the 11,000-volt bus and the transformers tend

to divert a lightning discharge to the lightning arresters rather than allow it to pass through the transformer.

Switchboards. *Alternating-Current.* The a.c. switchboard for a substation of this type consists of a panel carrying a high-tension oil switch, indicated in Figs. 178 and 179, on the opposite side of the wall from the transformers, and starting panels for applying reduced voltage to the rings of the synchronous converter.

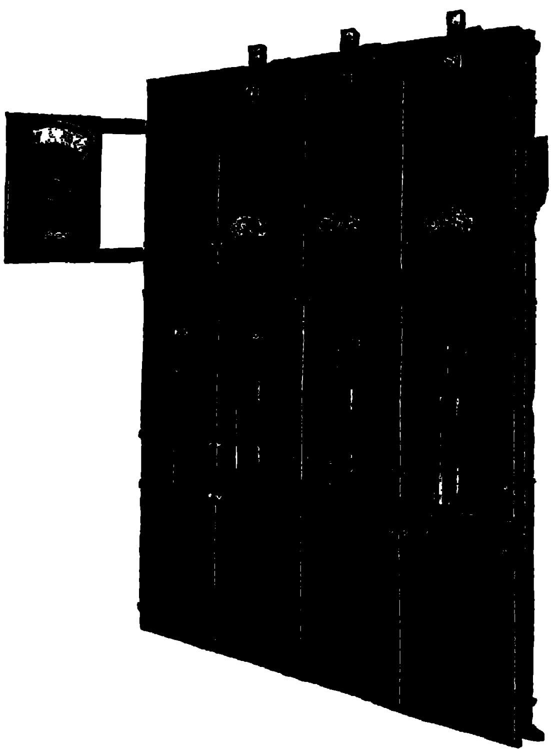


Fig. 180. 13,200-Volt Alternating-Current and 600-Volt Direct-Current Railway Substation Switchboard
Courtesy of General Electric Company, Schenectady, New York

Direct-Current. The d.c. panels include one panel for each converter and a feeder panel for each feeder cable. Swinging brackets are also provided on the end panels for indicating d.c. voltmeters. In Fig. 180 is illustrated a 13,200-volt a.c. panel adjoining a 600-volt d.c. machine panel and two feeder panels. It will be noted that the a.c. panel contains only a handle for

operating the oil switch and an overload tripping mechanism for opening the circuit under overload.

Each of the d.c. panels carries a circuit-breaker at the top for protection in case of overload, a line switch on the middle panel, and ammeters indicating the current being generated by the machine and the amount being distributed through each panel.

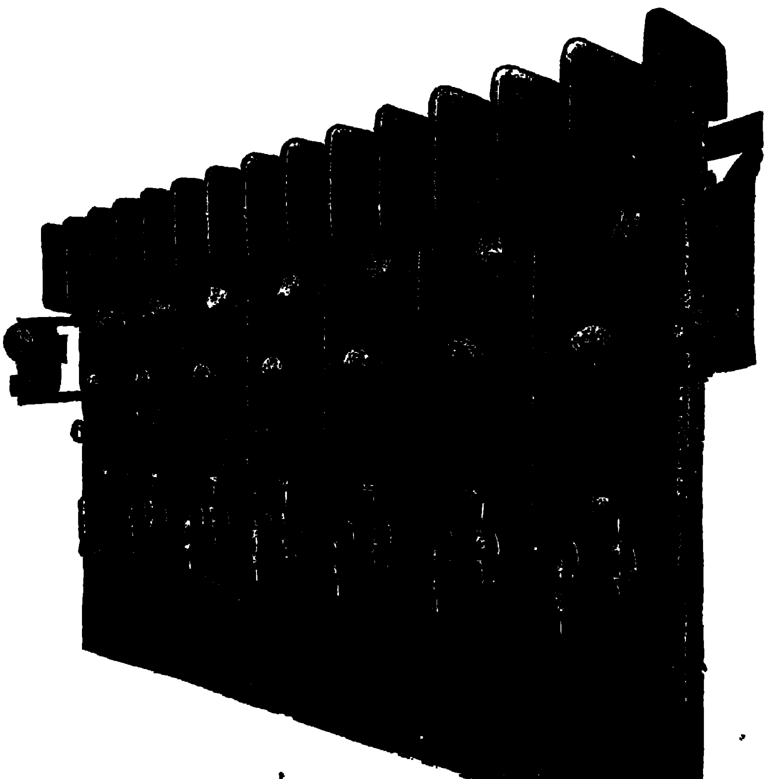


Fig. 181. 1200-Volt Direct-Current Switchboard
Courtesy of General Electric Company, Schenectady, New York

On the machine panel is a rheostat handle for controlling the synchronous converter field and a small switch for controlling the lighting circuit. Potential receptacles are located on each panel for phasing in the second machine or connecting the feeder to the bus.

1200- and 1500-Volt Stations. A 1200-volt d.c. switchboard controlling four 1200-volt synchronous converters and three feeder

circuits is shown in Fig. 181. The construction differs somewhat from the 600-volt type in order to obtain protection from the higher voltage. It will be noted that both the circuit-breaker and the line switch on these panels are operated through bell cranks and levers so that all 1200-volt parts are out of reach of the

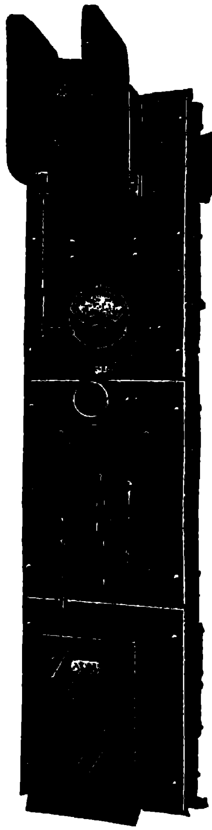


Fig. 182. Front of 1200-Volt Panel with Watt-Hour Meter for Two Synchronous Converters in Series
Courtesy of General Electric Company, Schenectady, New York

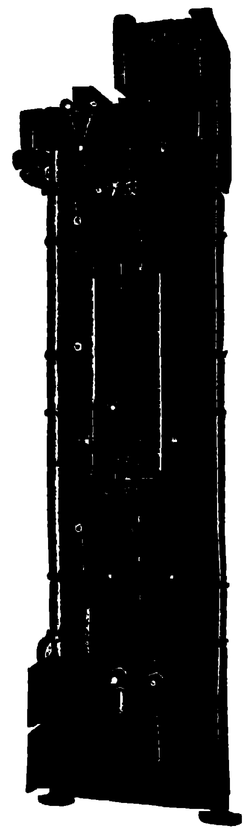


Fig. 183. Back View of Panel Shown in Fig. 182
Courtesy of General Electric Company, Schenectady, New York

operator. The operating handles are similar to those used on a.c. circuit-breakers, but the circuit-breaker handle is inverted with respect to the line switch in order to avoid confusion on the part of the operator. In case of overload the circuit-breaker trips free from the handle, differing in this respect from the lever switch.

The danger of a short-circuit being caused by the arcing of the 1200-volt circuit-breaker is avoided by the use of asbestos barriers mounted between the circuit-breakers and the switches and also at the ends of the board. An asbestos barrier is also placed along

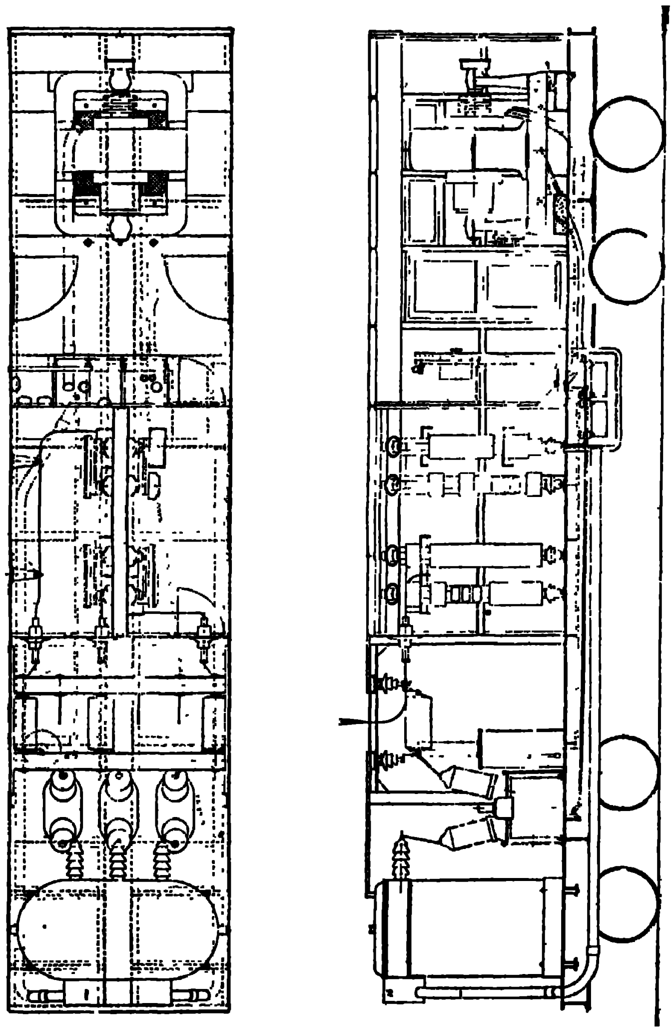


Fig. 184. Portable Railway Substation, 35,000-Volt Primary, Berkshire Street Railway Company
Courtesy of General Electric Company, Schenectady, New York

the top of the panel to prevent the possibility of an arc striking back to the pipe framework or to the metal parts.

The front and the back of a 1200-volt panel are shown in Figs. 182 and 183.

Portable Substations. Many railway systems use a complete substation outfit mounted in a steel or wooden car in such a manner that it can be transported over the line and located at any point in case of emergency. The equipment used for a portable substation is similar to that in a stationary installation except that various modifications are made to secure as compact

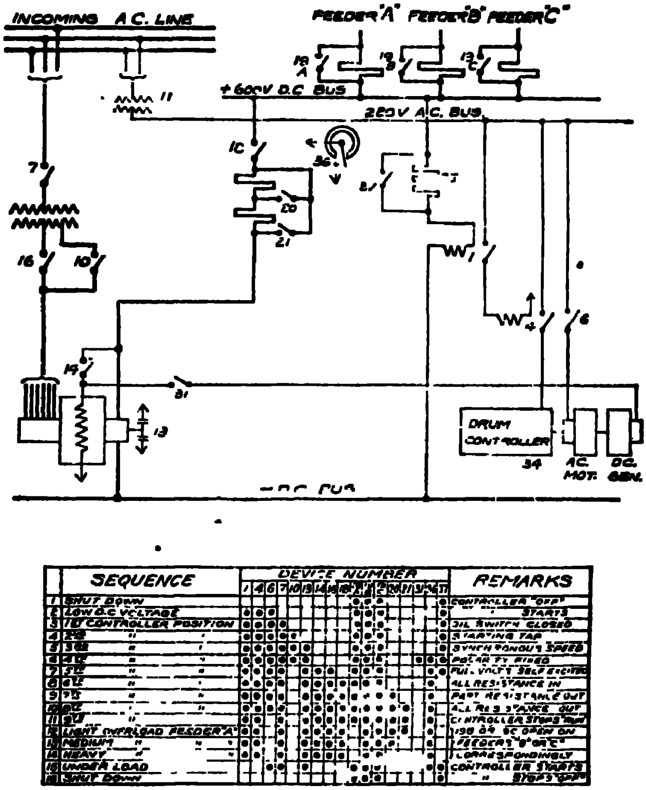


Fig. 185. Simplified Wiring Diagram and Table Showing Sequence of Automatic Railway Substation Operations

an arrangement as possible. The general location of apparatus in a 300-kilowatt portable substation of the semi-outdoor type is given in Fig. 184.

Automatic Substations. Recently considerable progress has been made in the design of automatic substations. This term means that the services of an operator are entirely eliminated, the station requiring only occasional inspection instead of continuous

attendance. This type of equipment was first tried out on interurban lines and has since been adapted to city service. The station capacity in most of the installations now running is from 300 to 1000 kilowatts each.

The purpose of the automatic substation is twofold: to save the cost of an operator over a period of two or three shifts per day; and to save power by shutting down the machinery when there is no demand for power on the line. The ordinary railway substation operates continuously from the time it is started in the morning until it is shut down at night. On interurban lines there are many periods during the day when there is no car on the section supplied by the station and as a result the machinery runs

Fig 186. Oakland Automatic Railway Substation of Rhode Island Company, Showing Control Panels and One of Two Synchronous Converters

without supplying current. The "running-light" losses, so-called, during the day amount to quite an appreciable figure.

The automatic substation consists of a number of electrical devices designed to perform the functions of the human attendant. When a car comes onto the division and begins to draw current, a reduction in the trolley voltage results, owing to the long feed from some other station, and a contact-making voltmeter operates, setting in motion a series of switches which connect the synchronous converter to the alternating current supply, bring it up to synchronism, close the field switch, and connect it to the station bus. Various protective devices are provided to ensure the correct functioning of the apparatus, and the station operates

until the demand for power disappears. When the car leaves the section, a current relay actuated by the amount of current being delivered by the station drops out, shutting down the machine. A motor-operated drum controller is used to ensure the correct sequence of operation of the various relays and contacts. In Fig. 185 are given a simplified wiring diagram of an automatic substation and a table showing the sequence of operations.

The development of the automatic substation affects the location of substations to a certain extent, owing to the decreased cost of operation. The interior of an automatic substation installed for the Rhode Island Company is shown in Fig. 186.

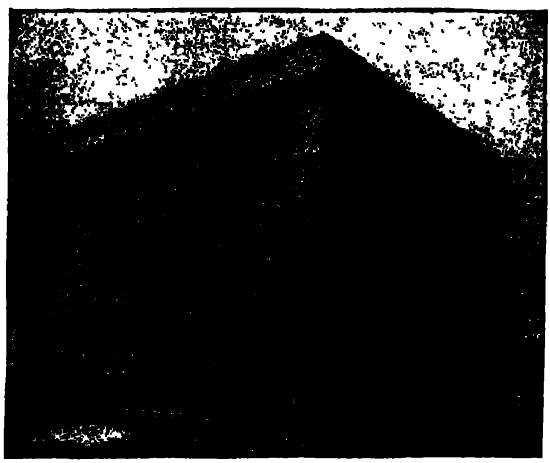


Fig 187. Brennan Automatic Railway Substation of Interurban Railway Company

The switchboard controls two 300-kilowatt synchronous converters, and provision is made for connecting the second machine to the line automatically when the load demand exceeds the capacity of one machine. In Fig. 187 is shown the exterior of a substation constructed by the Des Moines Interurban Railway, giving an idea of the economies possible with this type of equipment. The size of the station can be somewhat reduced, since no quarters are necessary for the operator. No heating equipment is required and, in place of windows at the bottom of the station, louvres are used for ventilation purposes, while small windows at the top of the building provide sufficient light for periodical inspection.

COST OF OPERATION

Cost of Electric Power Generation. It is the function of every power plant to generate power at the lowest possible cost per kilowatt hour. While at first glance it may seem a simple matter to measure the coal, water, supplies, and labor and thus determine the cost of electric power, there are other items which enter into the cost which should be considered. These are known as overhead charges and include interest, depreciation, maintenance, insurance, and taxes. These charges are logically considered a portion of the cost of energy when computed on a kilowatt-hour basis. It is a part of the designing engineer's duty to keep the overhead charges as low as possible; that is, the plant must be constructed with the minimum money investment, at the same time avoiding too rapid depreciation, too high maintenance cost, etc. If overhead charges are not taken into account, it may easily happen that a water-power plant which requires no expense for fuel may show a higher cost per kilowatt hour than a steam plant of the same capacity. In Figs. 188, 189, 190, and 191 the make-up of energy costs is shown graphically. In Fig. 188 the cost of fuel, of labor, and of sundries (oil, water, waste, etc.) for a number of stations is plotted in percentages of the total operating cost against the quantity of energy generated per year. The total of the three costs in each case is 100 per cent. There appears to be no definite law connecting these variables. An average value of cost of fuel is about 56 per cent, of labor about 28 per cent, and of sundries the balance of 100 per cent.

The relation of coal consumption to quantity of energy generated is given in Fig. 189. The value in the larger stations approaches 3 pounds of coal per kilowatt hour, but most modern steam-turbine plants of large capacity are able to reach a figure of from 1½ to 2 pounds. An idea of the amount of labor required in small stations is afforded by Fig. 190. There is great divergence in practice shown here, but the points give data for estimating the reasonableness of the number of men in a given plant.

Fig. 191 is a chart of great interest because it shows that the operating cost of energy bears a fairly systematic relation to the quantity generated. The cost seems to approach a value of 1 cent

per kilowatt hour. This is higher than is the rule in large plants, but appears not unreasonable in plants of the sizes indicated in Fig. 190.

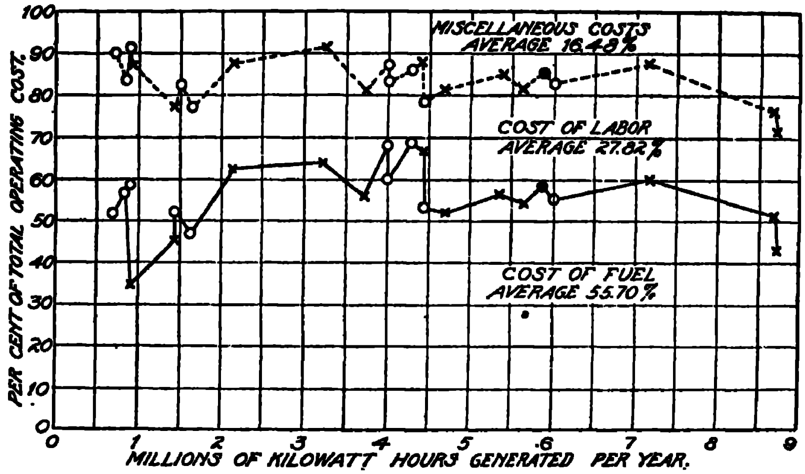


Fig. 188. Curve Showing Per Cent of Total Cost of Fuel, Labor, and Sundries for Given Quantity of Energy Generated Per Year

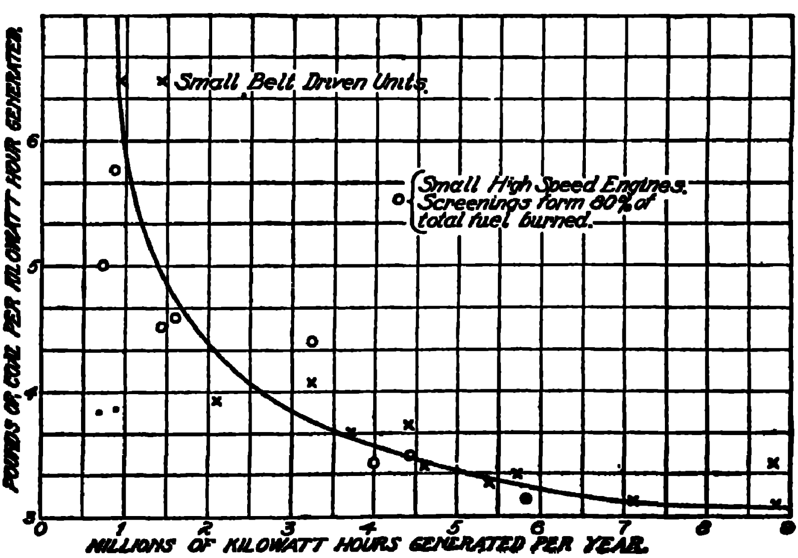


Fig. 189. Curve Showing Relation of Coal Consumption to Quantity of Energy Generated

Load Factor. The *load factor* of a power plant or, more properly, the *plant factor* is defined in the Standardization Rules

of the A.I.E.E. as: "The ratio of the average load to the rated capacity of the power plant, i.e., the aggregate ratings of the generators." This factor has an important bearing on the cost of electrical energy, since the equipment is not working at its maxi-

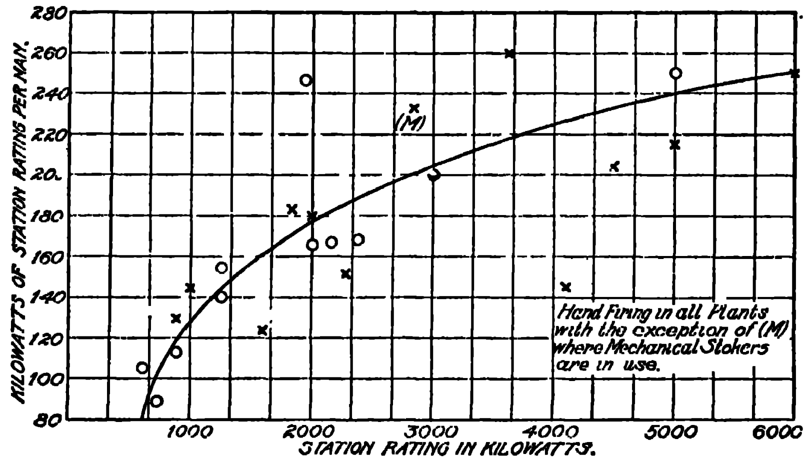


Fig. 190. Curve Showing Relation of Man Labor to Kilowatts Produced

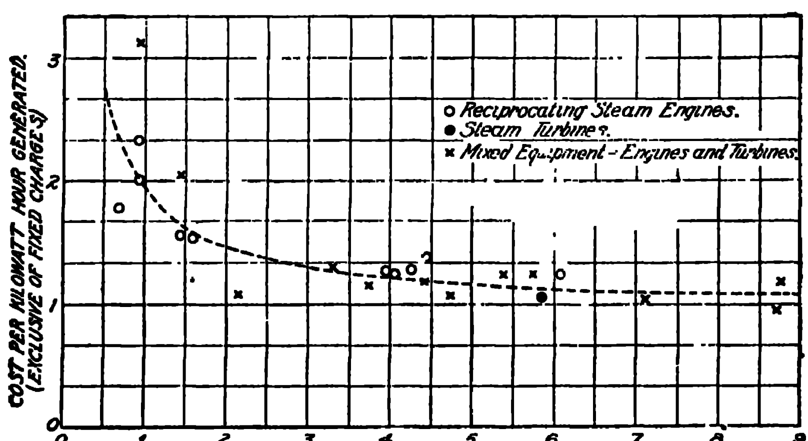


Fig. 191. Curve Showing Total Cost Per Kilowatt Hour Generated

mum efficiency, and a larger part of the plant expenses are just as heavy when operating partially loaded as at full capacity. There are many plants which operate at a low plant factor, Fig. 192. Large power producers are making a special effort to secure a sufficiently diversified load to ensure a high plant factor.

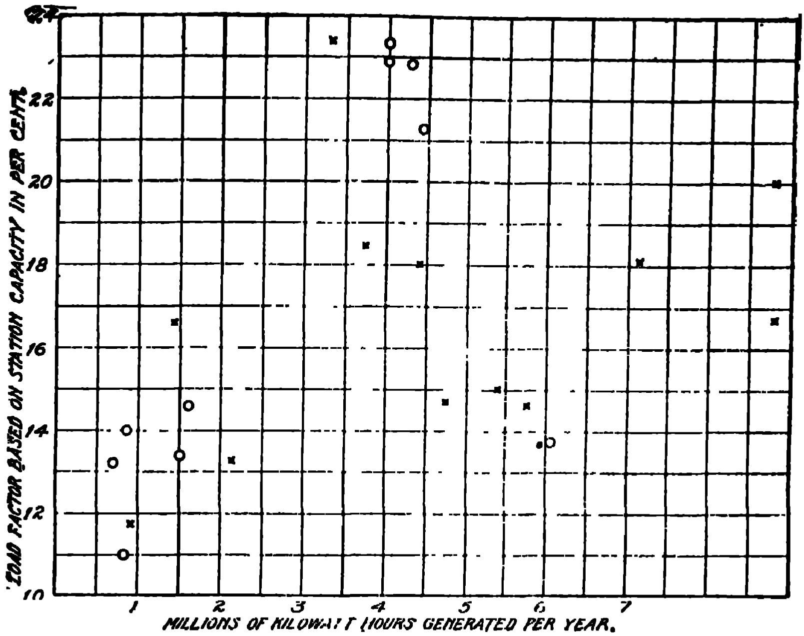


Fig. 192 Load Factor Percentages for Plants of Various Outputs

TRANSMISSION

Three-Phase vs. Single-Phase. Electric power is transmitted from the power station over three-phase a.c. wires, this system of transmission giving better efficiency than any other. A majority of the electric railways of this country use direct current either on the trolley or third rail, and the general scheme of distribution is shown in Fig. 193. Theoretically, the arrangement illustrated in Fig. 194 for a single-phase railway is much simpler than a d.c. system. In practice, however, it has not been found feasible to use single phase for interurban lines owing to the greater weight of the motor equipment necessary, the difficulty in operating a.c. cars where trolley voltage is not well maintained, and the undesirable effect of a short-circuit being impressed directly on the a.c. generator at the power house. Difficulties have also been encountered owing to disturbances on neighboring telegraph and telephone lines caused by electrostatic and electromagnetic interference. The single-phase system, however, has been found successful in the operation of heavy trunk lines where the amount of

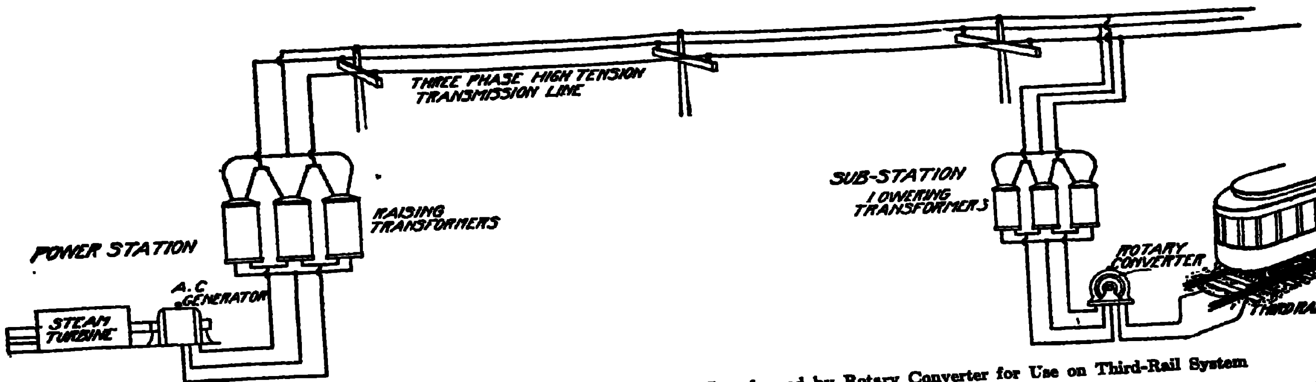


Fig. 193. Diagram of Connections for Three-Phase Alternating Current Transformed by Rotary Converter for Use on Third-Rail System

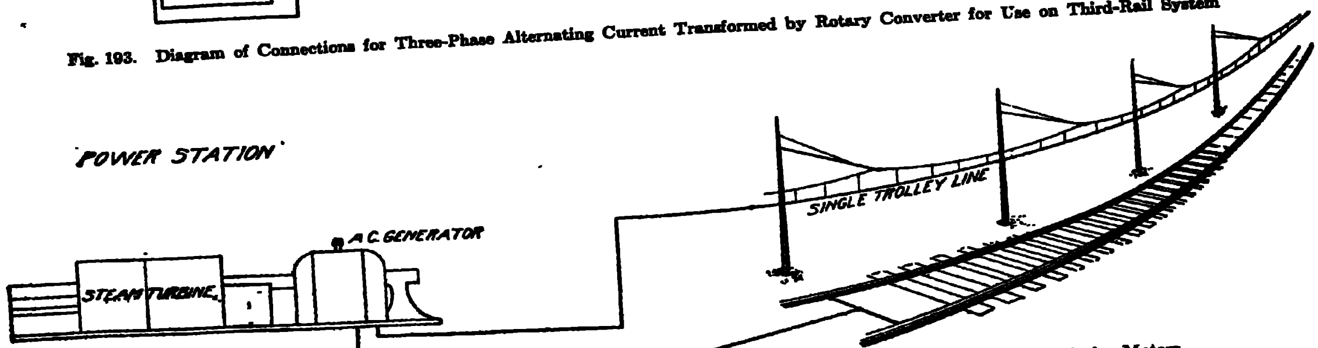


Fig. 194. Diagram of High-Tension Circuit Going Directly to Cars through Transformers into Single-Phase Series Motors

current required is sufficient to justify the installation of step-down transformer substations at suitable intervals to ensure correct trolley voltage.

Typical Three-Phase System. In Fig. 195 is given a diagrammatic layout of the New York Central electrification, showing the location of two turbine generating stations at Port Morris and Glenwood. Three-phase twenty-five-cycle current is generated in these plants at 11,000 volts and transmitted by means of underground cables and overhead transmission lines to nine substations located along the tracks of the railroad system. Synchronous converters in these stations transform the three-phase current to 660-volt direct current. Current at this potential is distributed along the tracks by means of an under-running third rail and carried to the motors of the locomotives and multiple-unit cars by means of a sliding contact or third-rail shoe. The layout shown illustrates quite clearly the flexibility of the three-phase transmission in combination with d.c. distribution. Since the installation was first put in operation a number of new units have been added in the several substations to handle additional load resulting from heavier railway traffic. In case the railway company desired to extend the electrification northward, the transmission lines could be easily extended and new substations constructed at suitable points without making any changes in the present equipment.

LINE PROBLEMS

Transmission Conductors. In congested city districts it is frequently necessary to install transmission conductors underground in order to avoid the possibility of accident due to the high voltage. Some form of conduit is usually installed and the conductors, in the form of three-phase lead-covered cables, Fig. 196, are pulled in between manholes located at suitable intervals. However, since it is difficult and expensive to insulate cables for very high voltages, the use of cables, either underground or overhead, for the high-tension circuits of electric-railway work is limited to cities where exposed high-tension wires are prohibited. Fortunately, in such cases the area of distribution is not great, and it is possible to use voltages which are practicable with cables. For further discussion of conductors see the article on "Distribution Systems."

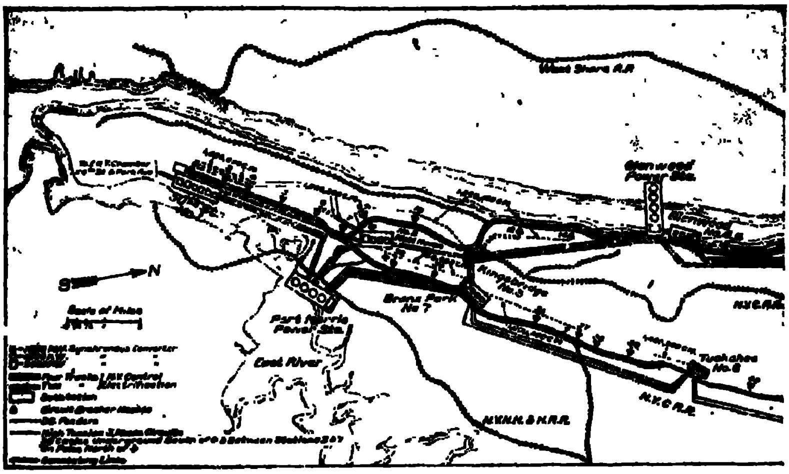


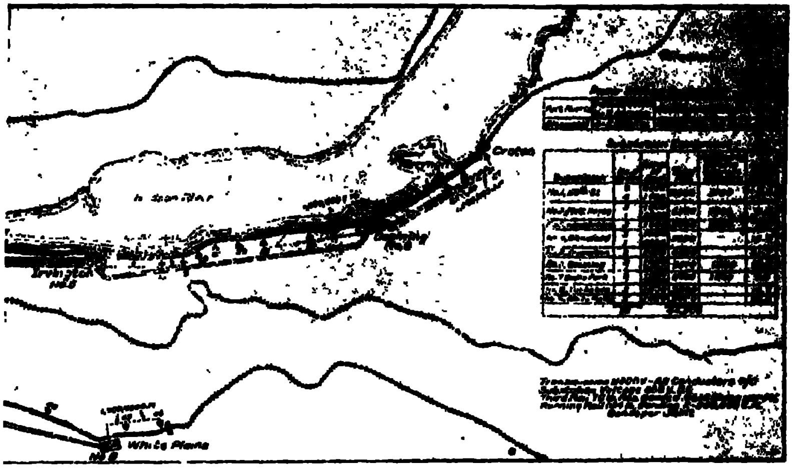
Fig. 195. Diagrammatic Layout of Power House Substations and

Determining Size of Conductor. The size of conductor is determined by the allowable drop in voltage, and in the case of transmission lines the tensile strength must also be considered. Both hard-drawn copper and aluminum are used for transmission lines, but as it is difficult to manufacture aluminum of absolutely uniform tensile strength, the cost for a similar service is usually somewhat greater with aluminum than with copper.

In determining the size of wire to be used on a pole transmission the mechanical strength is determined by the strains due to stretching from pole to pole and the possibility of heavy accumulations of ice in the cold weather, as well as to contraction of the wire due to low temperature. Wires smaller than No. 4 B. & S. gage are not suitable for transmission work.

A general rule for determining the size of conductor, commonly known as *Kelvin's law,* is as follows: Such a size of conductor should be used that the interest on the money invested in the wire and such auxiliaries as vary with the size of the wire shall be equal to the value of the energy annually lost in the line. This is a formal way of stating that if an additional expenditure for copper or aluminum will result in a saving greater then the cost, it will pay, and vice versa.

Determining Voltage. The transmission voltage of a line is selected on the basis of experience, and there is no simple rule for



Transmission Lines of New York Central Railroad Electrification

determining the proper value. In general, as the voltage is raised, the cross-sectional area of the conductor may be reduced with the same amount of power transmitted. With the same power the cross-sectional area of conductor is theoretically inversely proportional to the square of the voltage. This follows because, if the power is to remain unchanged, the current is inversely proportional to the voltage, the power being EI (the product of the voltage and the current). Thus, if the value of EI is to remain the same and the value of E is doubled, the value of I must be halved. In order to halve the current I $\left(\text{which equals } \frac{E}{R}\right)$ when the voltage E is doubled, the resistance R must be increased in the same ratio as the square of the voltage, that is, by four. In order to increase the resistance four times, or, in general terms, in direct proportion to the square of the voltage, the area of the conductor is decreased four times. Thus, with the power unchanged, as the square of the voltage increases, the area of the conductor decreases. It is quite possible, however, in a given case, that the reduction in the size of wire may be limited by mechanical considerations, so that it is not always possible to take full advantage of the increased voltage. An increase in the voltage is accompanied by additional expense for insulators, for it is more difficult to insulate a high-tension line than a low-tension line. Not only are the high-tension

insulators more expensive, but they are more difficult to maintain. On the whole, therefore, a moderate transmission voltage is chosen which will give the most economical all-round results. At present the upper limit of voltage is about 110,000, but this is extreme. About 30,000 volts may be considered conservative practice for

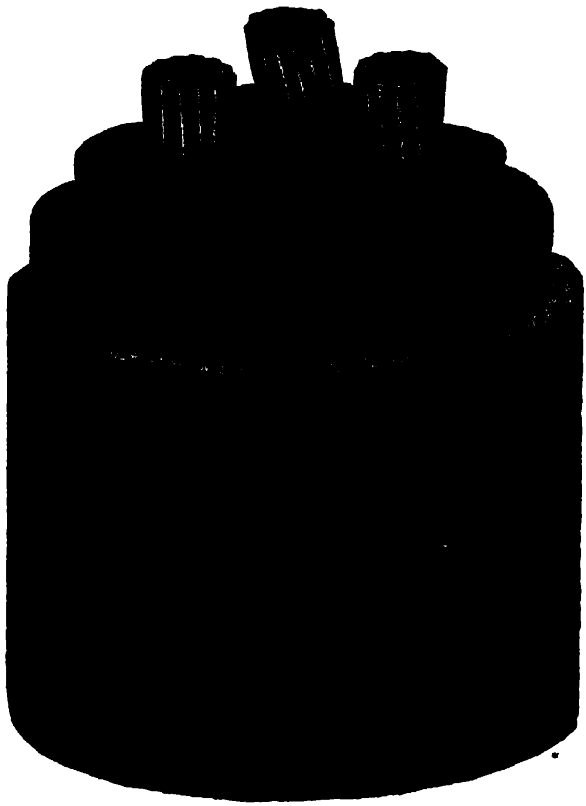


Fig. 196. Three-Phase Lead-Covered Transmission Cable Insulated for 25,000 Volts
Courtesy of General Electric Company, Schenectady, New York

railway work. Over small areas electromotive forces of 6,600 volts are used even with very large quantities of power.

Poles and Towers. Transmission wires are supported on wooden poles or on steel towers. The latter are used to an increasing extent because they are durable and permit the use of long spans, as they can be constructed of any necessary height.

Concrete poles are successfully made and undoubtedly have a future before them. Wooden poles are still in general use, however, and are made of Georgia pine, white cedar, chestnut, redwood, and other more or less durable woods. The variety used in any locality depends to some extent upon the natural timber of the region. The poles are not usually dressed, although they are sometimes dressed to octagon form where appearance is important.

To the poles are attached Georgia pine crossarms, the poles being notched, or gained, to receive them. The crossarms are held in place on the poles by bolts passing entirely through both. The crossarms are braced with galvanized-iron straps, which are placed at an angle of about 45 degrees. The braces are attached to the crossarms by carriage bolts and to the poles by lag screws. The crossarms are bored to receive locust pins or iron bolts, upon which are mounted the glass or porcelain insulators. The crossarms are thoroughly coated with metallic paint, and their upper surfaces are rounded so that they will shed water readily.

Concrete poles are molded in a taper form somewhat similar to the shape of wooden poles but of nearly square cross-section. The corners are chamfered to prevent chipping and to facilitate molding. The poles are reinforced with steel rods and the gains for the crossarms are molded in the proper positions. Steps are also molded in the poles, as climbing-irons would be useless in this case. While these poles are very heavy, they will undoubtedly prove durable, and the results of the early installations will be watched with interest.

Poles are set in the ground 6 feet, more or less, depending upon the height of the pole and the character of the soil.

The construction of a single-track interurban trolley road is represented in Fig. 197, which shows plainly at the left the construction of the transmission line. The same pole line in this case serves also to support the trolley brackets and to carry the telephone line used for dispatching. In this illustration the upper crossarms are provided with six insulators, one three-phase line being mounted on each side of the pole.

Steel structures for supporting transmission lines are coming into use. As they are more expensive, in first cost at least, than

wooden poles, they usually must be placed at greater distances apart in order to render their use economically practicable. Where

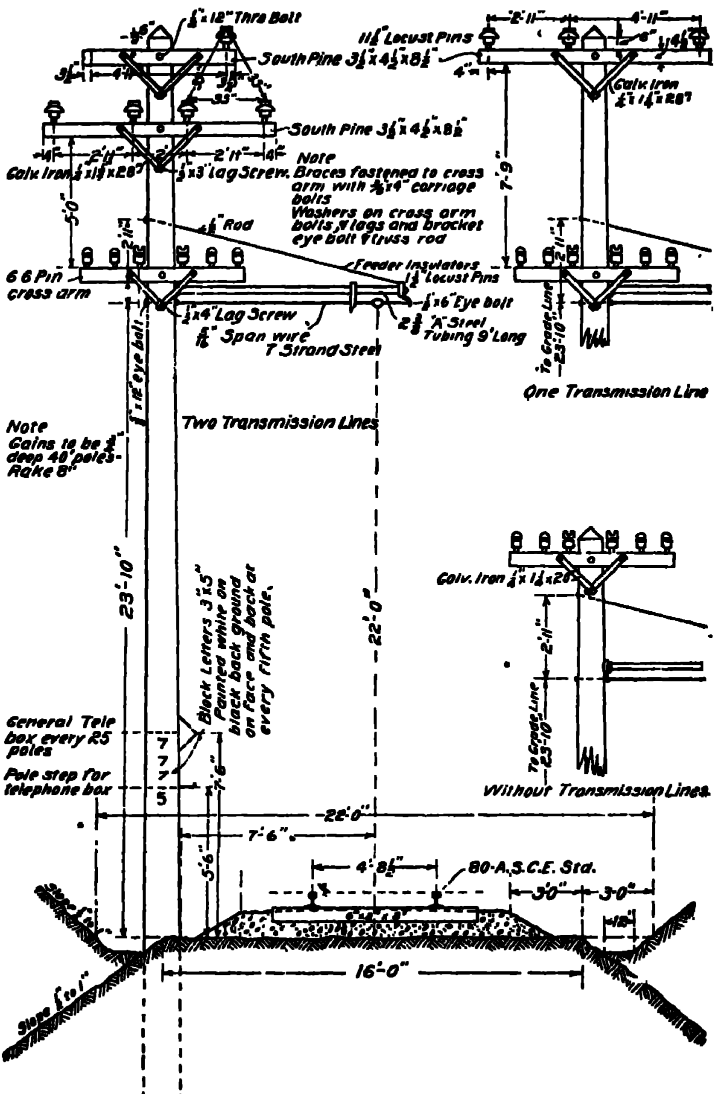


Fig. 197. Diagram of Construction of Single-Track Interurban Trolley Road

wooden poles are placed from fifty to thirty to the mile, towers may be placed from thirty to as few as ten to the mile.

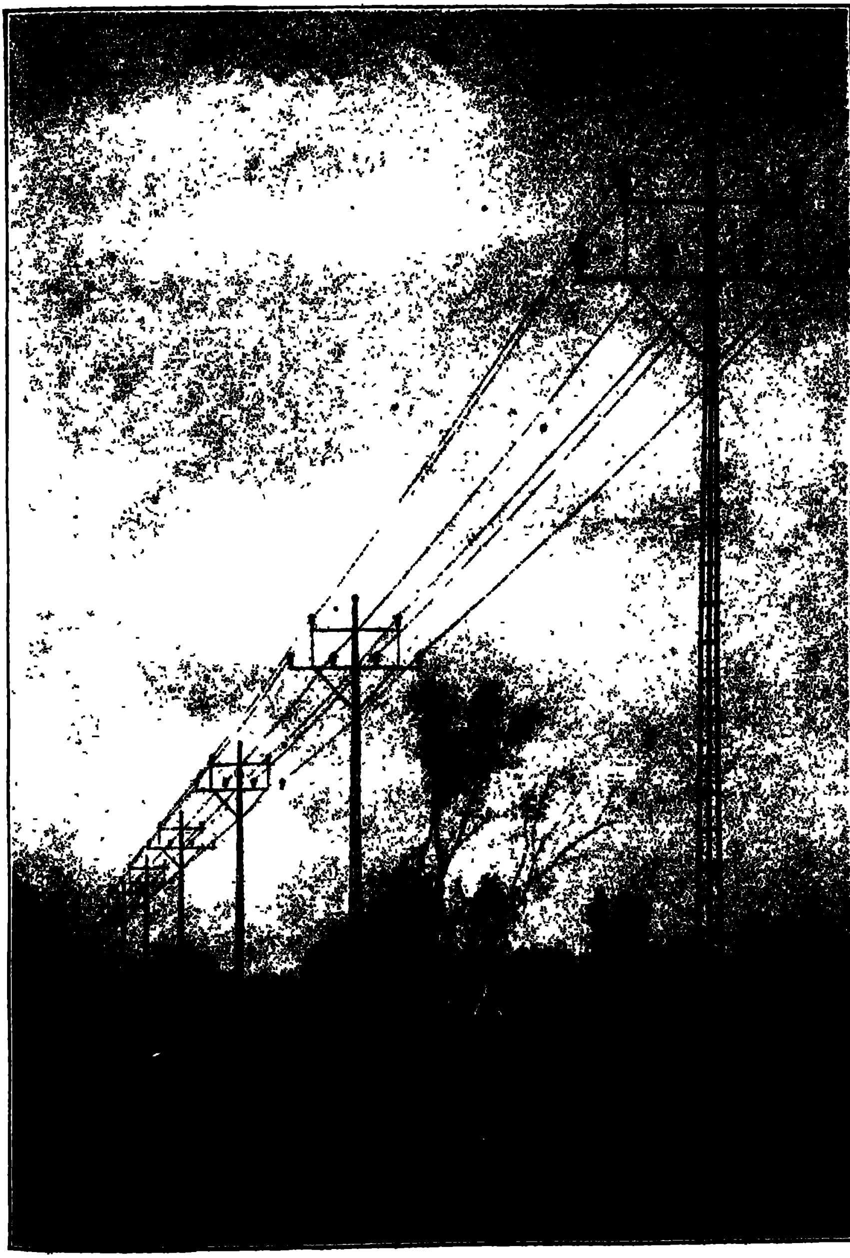


Fig. 198. Steel Pole Construction for High-Tension Circuit

The steel tower, built up of light galvanized-iron angles, was in use for supporting windmills before it was required for electric power-transmission purposes, and it was a comparatively simple matter to adapt it to a new use. Towers of practically the same form as used in windmill practice are used in many transmission lines. There are other forms, however, which have been developed particularly for this service. Fig. 198 shows a steel substitute for the wooden pole, which consists of three light steel uprights separated by crosspieces. Steel crossarms form a part of the structure. The arrangement of insulators is as in the preceding example. A flat structure is shown in Fig. 199, which is strongly braced for side strains but offers no resistance along the direction of the transmission line. The line, in this case, is anchored by guy wires at intervals. In Fig. 200 is shown a slightly different form in which the two transmission lines provided for have their insulators mounted one above the other. In both of the flat structures there are

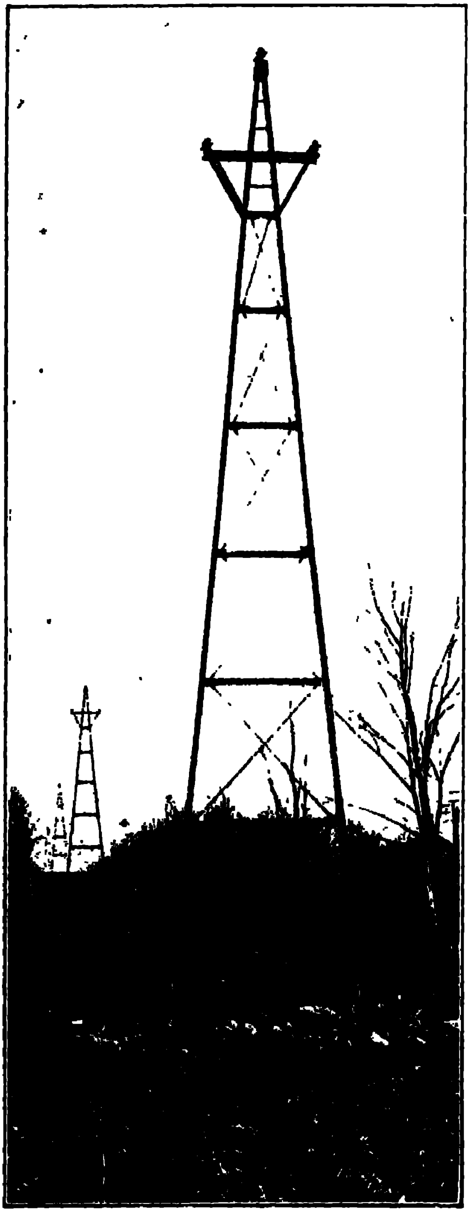


Fig. 199. Steel Tower with Side Bracing Only

crosspieces every few feet, and the whole is strongly braced by light diagonal wires attached to the corners of the spaces thus formed.

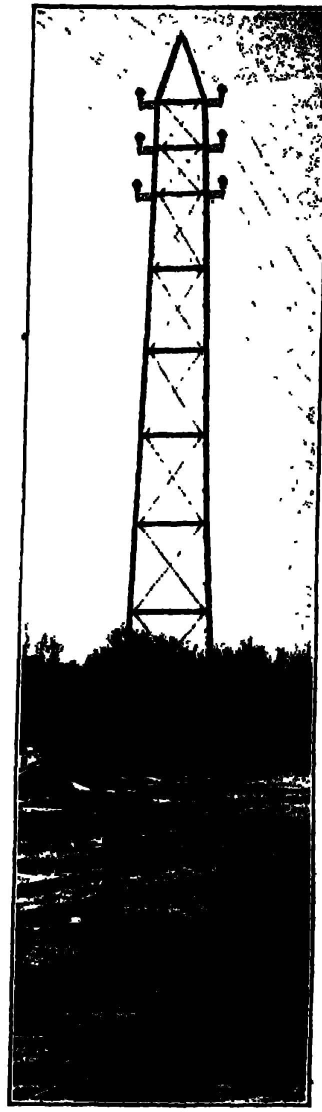


Fig. 200. Steel Tower with Insulators Mounted One above the Other

Insulators. In high-tension transmission lines for railway work both glass and porcelain insulators are employed. Glass is cheap, and it may be easily inspected for flaws; porcelain is, however, usually considered more reliable. The insulators are made up in shells which are cemented together, the shells of small insulators being often cemented by the glaze on the porcelain. The shells are so designed as to form "petticoats" which furnish a long leakage path for the current over the surface and thus reduce the leakage.

The insulator is made of such size that the striking distance from the conductor to the pin shall be great enough to prevent the breaking down of the air and the consequent short-circuit of the line. On the top of the insulator is a groove in which the conductor lies, and below is a flange to which some kind of a binding or clamping device is attached.

Typical high-tension insulators are shown in Figs. 201 and 202. The form of insulator described is the pin insulator, so called on account of the manner of mounting. This form has its limitations because of the mechanical weakness of the pin in very high insulators. A new type has, therefore, been developed in which the conductor hangs from the insulator and the insulator from the crossarm. Fig. 203 shows a very modern high-tension tower equipped with

suspension insulators. The wires, which are not shown, hang from the bottom insulators. The insulator is seen to consist

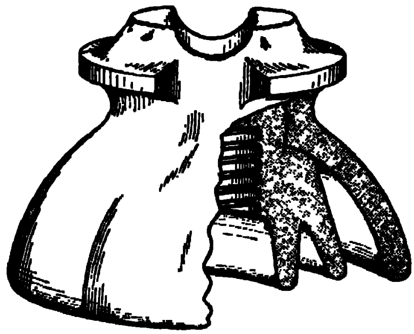


Fig. 201. High-Tension Pin Insulator

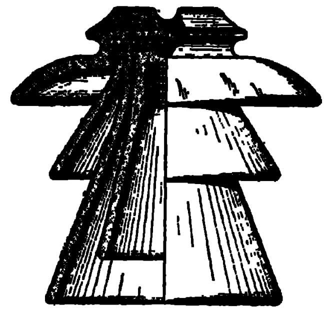


Fig. 202. High-Tension "Petticoat" Pin Insulator

of a string of shells, the number of shells being determined by the voltage which is to be insulated against. In this case the line is able to carry 150,000 volts and each insulator has eight sections.

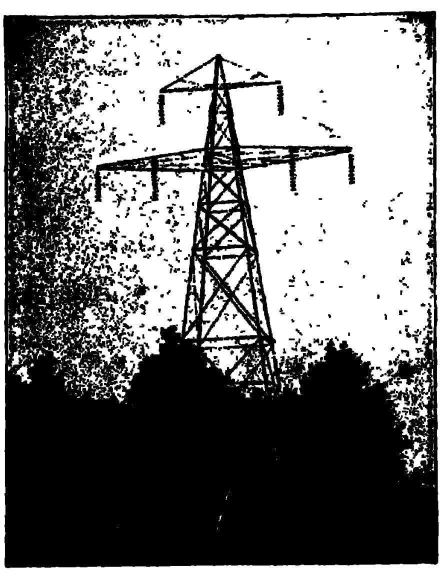


Fig. 203. Modern High-Tension Tower with Suspension Insulators

In Fig. 204 is shown a section of a typical suspension insulator. It is a porcelain shell with galvanized-iron fittings by which it may be attached to similar shells above and below.

DISTRIBUTION SYSTEM

Component Parts. The elements of the distribution system are: the trolley wire or third rail through which the current flows to the cars; the feeders which supplement the trolley wire or third rail and supply connection to substations; and the return circuit, usually consisting of the running rails, and, in some cases,

an auxiliary negative feeder through which the current travels back to the station.

OVERHEAD CONSTRUCTION

Types. On city lines and on some light interurban and suburban roads the so-called direct-suspended trolley wire is used with bracket construction for single track and span construction for double track and on congested city streets. On high-speed interurban lines and for steam railway electrification a catenary construction is employed, which is much more suitable for high-speed running and is also adapted to pantograph collectors.

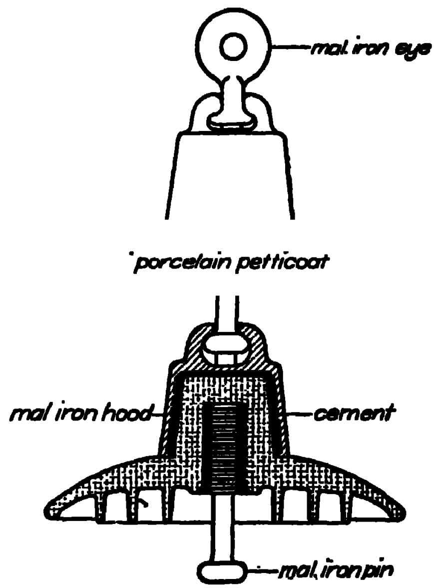


Fig. 204. Section of Suspension Insulator

Section Insulators. It is frequently desirable to disconnect the power from certain sections of a trolley line without interrupting the supply to other portions of the system, and for this purpose section insulators are installed at regular intervals. Such an insulator usually consists of terminal clamps for the trolley wire connected by wooden insulating pieces, one type being shown in Fig. 205. The trolley wires ending at the wooden section are connected to a pole, and a single-pole switch is provided for short-circuiting the insulator under normal conditions. In a large city system it sometimes happens that a short-circuit may occur, owing to the grounding of a trolley wire, causing the circuit-breakers in the power station to open on account of the heavy current flowing over the circuit of low resistance. Should a condition of this kind continue for any length of time, the entire power station would be disconnected from the trolley circuit until repairs were made. This possibility is prevented by the use of individual

feeders, each of which has its own breaker, so that the effect of the accident is localized and the service is continued on the other parts of the system.

Supporting Wires on Curves. In supporting the trolley wire on curves it is necessary to pull the wire from one side in order to make it conform as nearly as possible to the curvature of the track. The method employed on a 90-degree curve is illustrated in Figs. 206 and 207. The backbone type of construction, shown in Fig. 207, is the simplest method of handling a trolley wire on the curves. Local conditions must be considered in determining how the wire must be supported.

Direct-Suspended Trolley. In the direct-suspended type of construction, as indicated by the designation, the trolley wire is supported directly on the cross span wire or bracket by means of

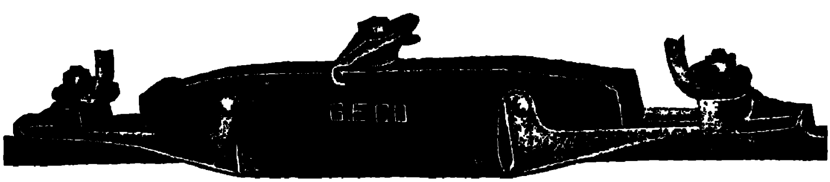


Fig. 205. Section Insulator for Trolley Line
Courtesy of General Electric Company, Schenectady, New York

suitable hangers and attaching devices, called ears, which permit the trolley wheel to pass without interference. The trolley wire most commonly used is the grooved type, but wire with a figure-eight section, Fig. 208, and round wire, Fig. 209, are also used. The size most commonly found is No. 0000 B.&S. gage, although many lines use as small as No. 00. With either the figure-eight or the grooved wire, supporting clamps are used which fasten to the upper part of the wire, leaving a smooth surface underneath for passage of the trolley wheel. With the round trolley wire the ear is soldered to the wire. A hanger and an ear for use with round wire are illustrated in Fig. 210.

Hanger. In Fig. 211 is shown a cross-sectional view of a hanger similar to the one in Fig. 210. The head of the bolt is molded to the cap *C*, Fig. 210, which is of molded insulating compound. The completed hanger is assembled so that the span

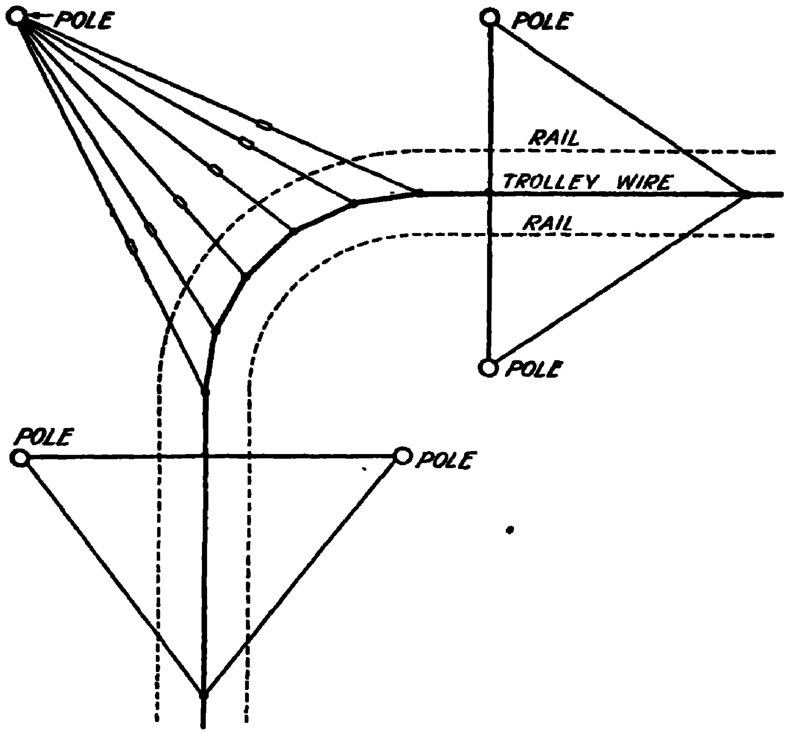


Fig. 206. Line Construction on Curve, Using Five Poles

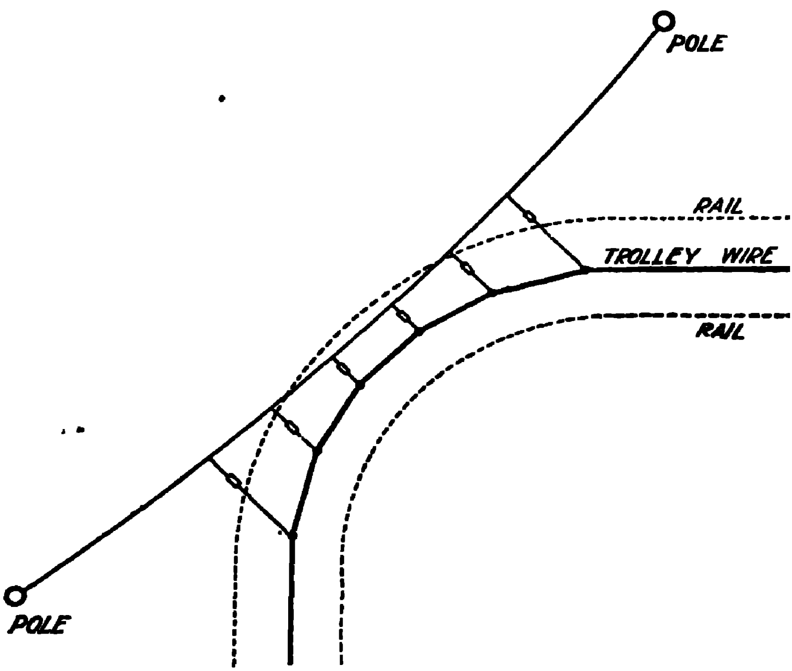


Fig. 207. Simple Curve Suspension, Using Two Poles

wire or supporting bracket is completely insulated from the live trolley wire. In the illustration the span wire passes through the clamp *B*, which is bent around it for permanent fastening. There are other forms of hanger, two of which are shown in part section in Figs. 212 and 213.

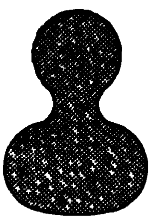


Fig. 208. Section of Figure-Eight Trolley Wire

Clamp. The construction of clamps used for supporting grooved and figure-eight wires is shown clearly in Figs. 214, 215, and 216. There are other devices for performing the same duty, all of very simple construction and designed to be assembled easily and quickly.

Span-Wire Construction. The supporting wires where span construction is used are usually of galvanized, stranded, steel cable. In order to increase the insulation between the trolley wire and the supporting structure, strain insulators, so-called, Fig. 217, are placed in the span wire. A strain insulator is adapted to withstand the great tension which is necessary in order to tighten the wire for supporting the trolley line and insulating equipment.

Wherever possible, wooden poles are used on account of their low cost. In city streets tubular steel poles and, in some cases, reinforced concrete poles are commonly used. A simple span-wire construction for a single-track interurban line is represented in Fig. 218.

Fig. 209. Section of Ear with Trolley Wire Soldered in Place

Bracket Construction. The cheapest method of trolley construction is the bracket type, Figs. 219, 220, and 221, in which the trolley wire is supported directly from iron brackets mounted on a pole at one side of the track. This bracket may be either of angle or pipe construction, and the supporting end is reinforced by attaching a brace, which is carried to a point 2 feet or thereabouts above the point of attachment of the bracket. Some flexibility in the support of the trolley wire is secured by hanging a short span of wire between the pole and a projection from the outer end of the bracket. This allows a small motion in a vertical

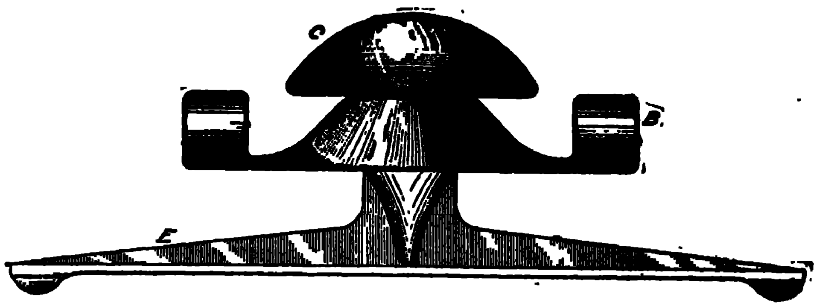


Fig. 210. Hanger and Ear for Round Trolley Wire

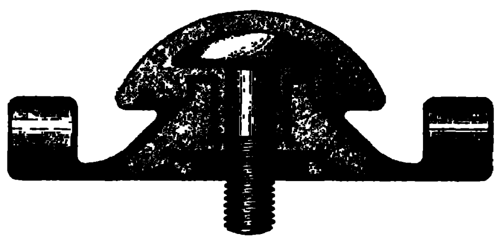


Fig. 211. Cross-Section of Hanger, Showing Construction

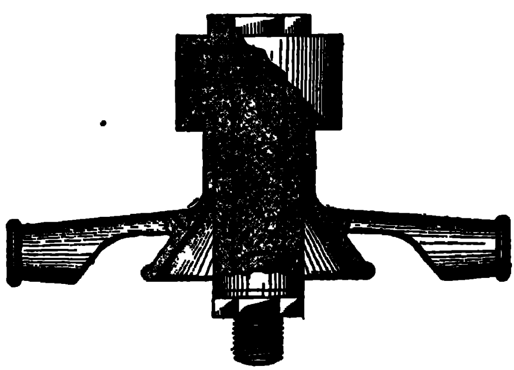


Fig. 212. Section of Hanger

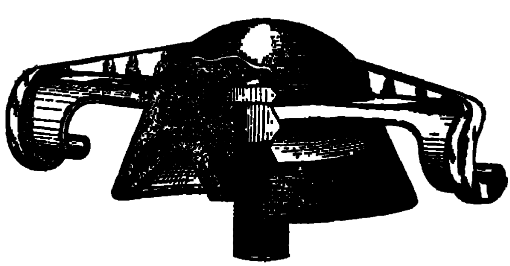


Fig. 213. Section of Hanger

direction upon the passage of the trolley and improves the flexibility of the construction.

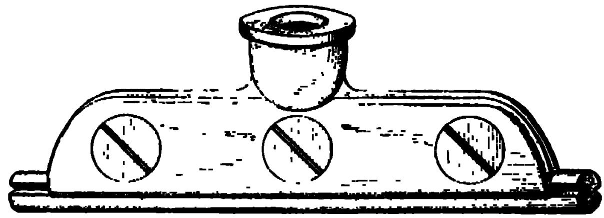


Fig. 214 Clamp Used with Grooved Trolley Wire

Catenary Construction. The direct-suspended type of construction, either span or bracket type, requires supports at points

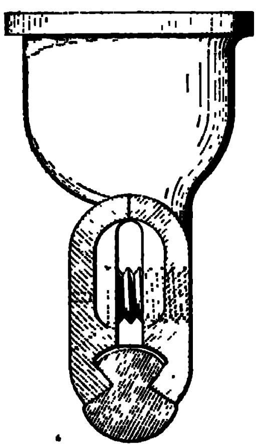


Fig. 215 Section through Clamp Shown in Fig 214

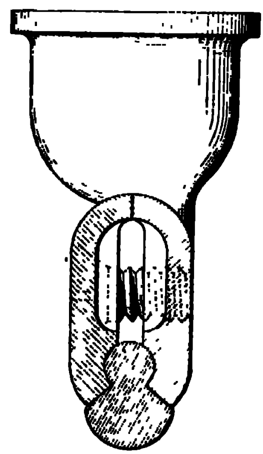


Fig. 216 Section through Clamp for Figure-Eight Wire

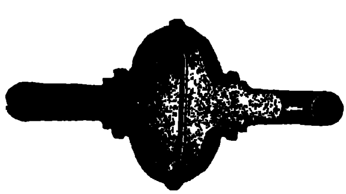


Fig. 217. Strain Insulator

not more than 100 feet apart, and even under these conditions there is an appreciable sag of the wire midway between supporting points. This condition is objectionable with high-speed running, since the trolley wire is carried somewhat above the point of support by the traveling trolley wheel and, upon reaching the point of support, strikes the hanger a heavy blow, materially

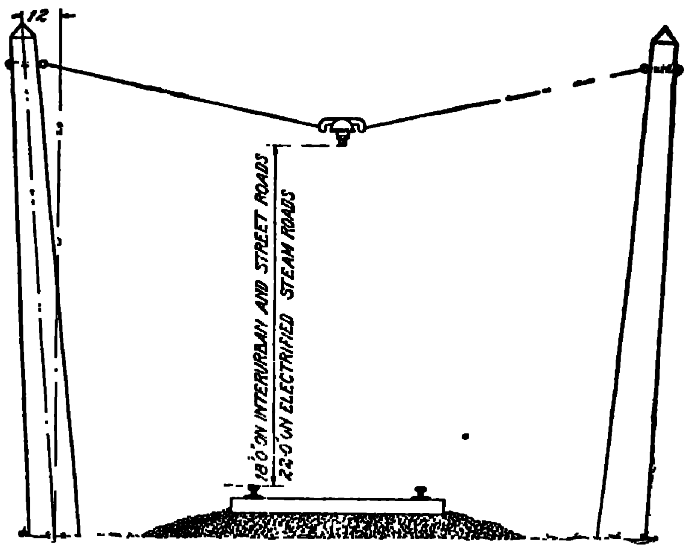


Fig. 218 Span Construction for Single Trolley Wire

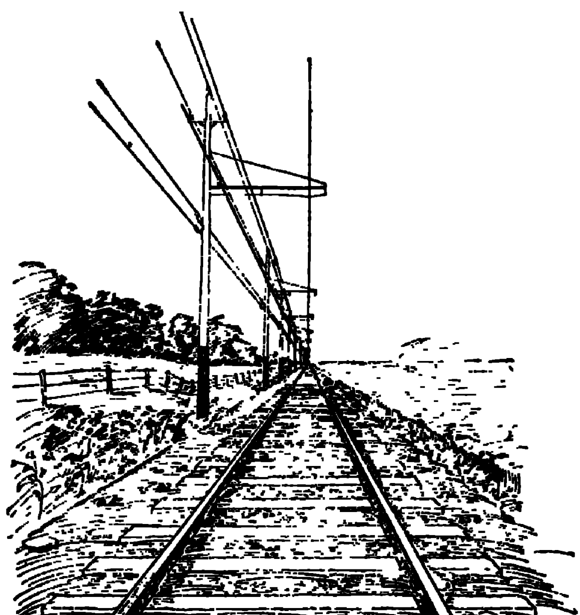


Fig. 219. Bracket Line Construction

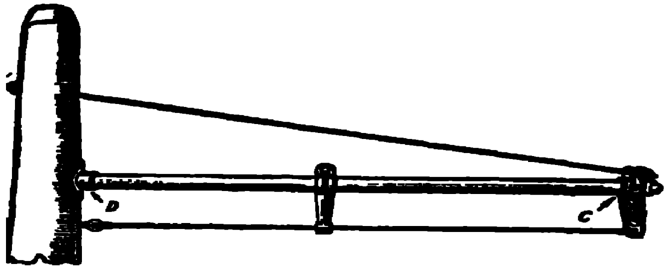


Fig 220. One Type of Bracket for Trolley Line

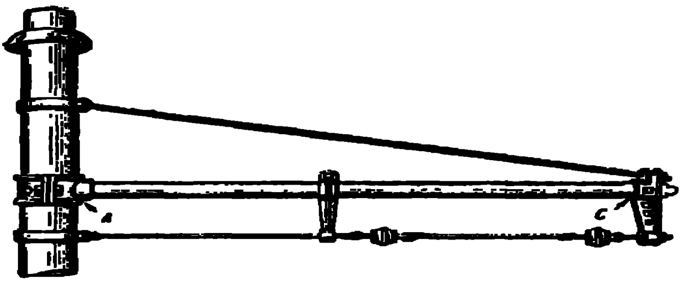


Fig. 221. Bracket Used on Metal Poles

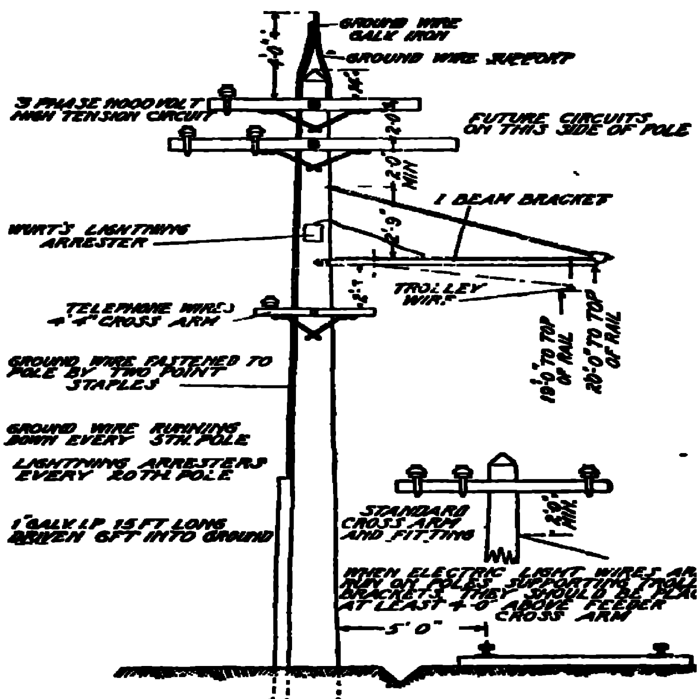


Fig. 222. Catenary Line Construction, Messenger Wire Being Strung on Bracket

reducing the life of both the trolley wire and the hanger. With pantograph operation it is practically impossible to use direct suspension, since the projecting portions of the collector would strike the supporting bracket or span-wires. In order to provide

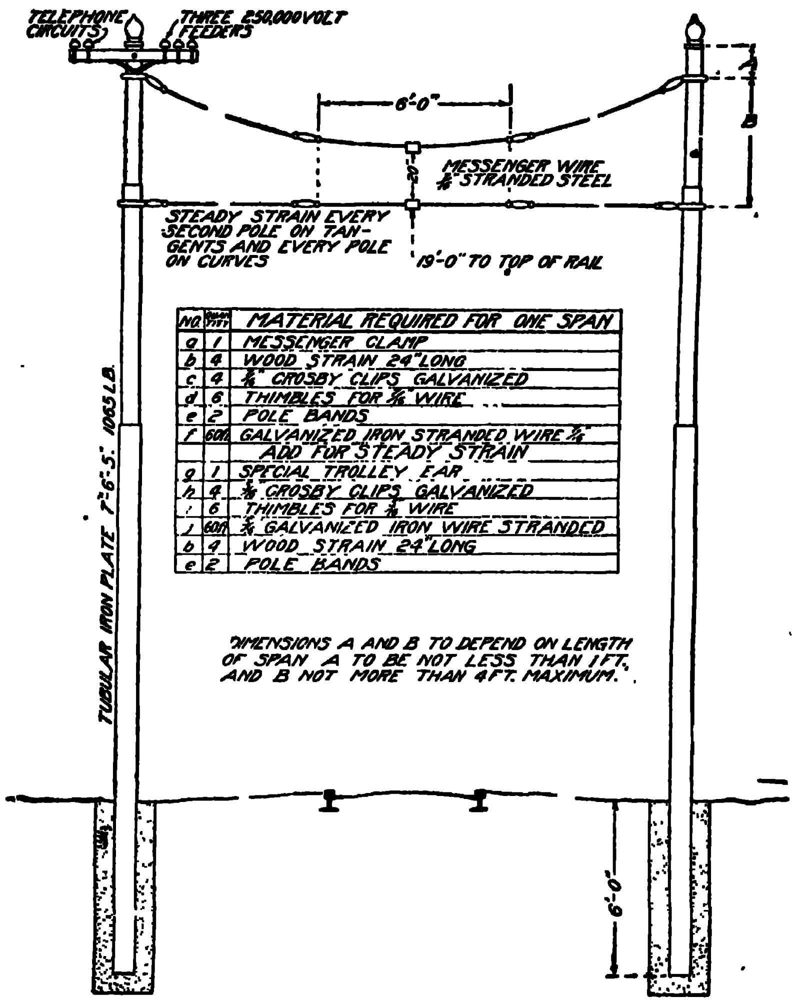


Fig. 223. Span Construction of Catenary Type

a suitable trolley wire for high-speed and pantograph work, the catenary method of support is used. In general, in this type of construction, Figs. 222, 223, and 224, there is a steel messenger wire insulated from the supporting structure, and the contact

wire is supported from the messenger wire by hangers located at equal intervals. By using hangers of unequal lengths to conform to the sag of the messenger it is possible to string the trolley wire on approximately a horizontal line. Catenary construction is known as three point, five point, or eleven point, as the case may be, depending upon the number of supporting hangers.

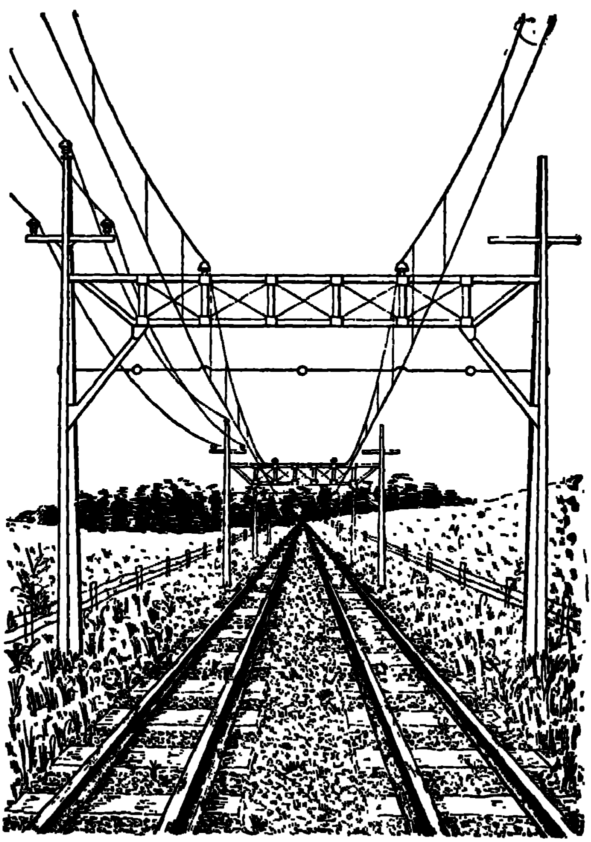


Fig. 224. Catenary System on Light Brace Construction

With this type of construction it is possible to obtain a well-constructed collecting system with wood poles at intervals of 150 feet on tangent track. With steel-bridge construction supporting points are as far as 300 feet apart.

Types. One of the important features of catenary construction developed in recent years is the so-called loop hanger shown

in Fig. 225, which allows the pantograph or trolley pole to lift the contact wire slightly without lifting the messenger itself. This gives a very flexible contact and perceptibly decreases the sparking at supporting points during heavy current collection. A still more effective method of catenary support is illustrated by the Chicago, Milwaukee and St. Paul Railway electrification, in which two trolley wires are suspended side by side, supported by hangers at alternate points so that when the collector strikes one hanger the other trolley wire is at mid-span. This type of construction, Figs. 226 and 227, of course, is suitable only for heavy current collection where two trolley wires are desirable for feeder capacity as well as for collection purposes. Another form of catenary construction, Fig. 228,

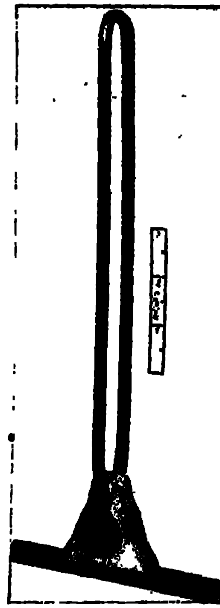


Fig. 225. General Electric Catenary Hanger

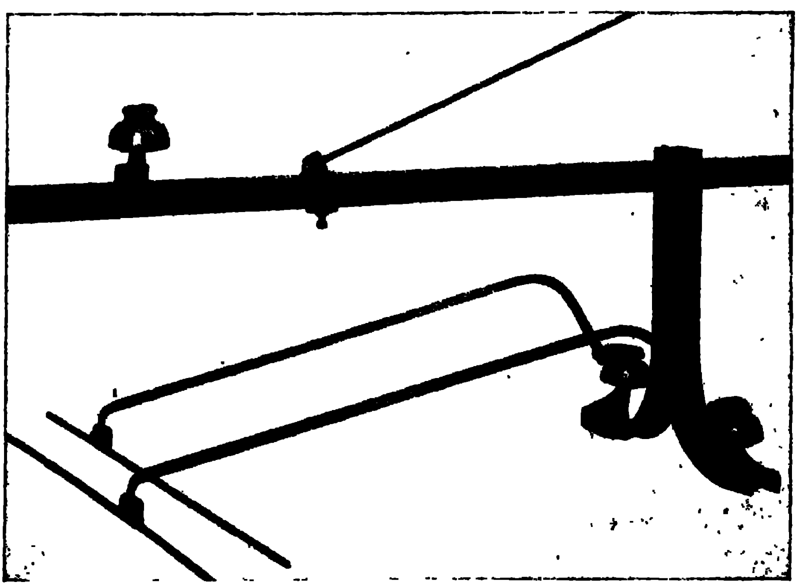


Fig. 226. Steady Brace for Two Trolley Wires, Roller and Slider Trolleys Mounted on T Iron Bracket

Courtesy of General Electric Company, Schenectady, New York

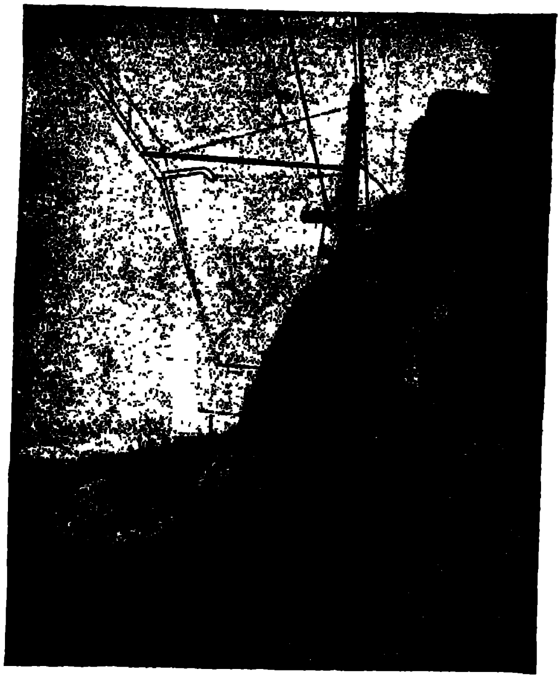


Fig. 227. Bracket Construction on Light Curves
Courtesy of General Electric Company, Schenectady, New York

Fig. 228. Freight Train on New York, New Haven and Hartford Railroad. Note Double Catenary Trolley
Courtesy of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pennsylvania

used by the Pennsylvania Railroad at Philadelphia, by the New Haven, and by some other a.c. roads, is the so-called double catenary, the contact wire being fastened to the current-carrying conductor which is supported by the hangers. The object of this double suspension is to secure a more uniform support, thus avoiding the possibility of sparking at contact points.

THIRD-RAIL CONSTRUCTION

Extent of Use. Under certain conditions it is desirable to use third-rail conductors for distribution of direct current; this was especially true before the advent of the higher d.c. voltages. Third-rail construction is used extensively on subway and elevated systems and on several terminal divisions where overhead construction is undesirable.

Rails. In this country there are two types of third-rail construction in use, designated, respectively, as over-running and under-running. Ordinarily the conductor rail is of standard T section and may be of the same composition as the running rails. A more desirable type of rail, however, is made up especially for the purpose and is of soft steel of high electrical conductivity. The weight of conductor rails varies from 40 pounds per yard* to 150 pounds per yard in the case of the special section used on the Pennsylvania Terminal at New York and on the Long Island Railroad. The conductor rail is supported on insulators which combine good mechanical strength with good insulating qualities. Iron or steel is usually employed for mechanical strength, and porcelain or hard insulating composition for dielectric strength.

Over-Running Construction. A simple insulator for the over-running type of construction is shown in Fig. 229. This consists of an iron base with holes to permit screwing to the tie, which is extended to a point beyond the clearance limits of the road. On the base is a block of molded insulating material, on the top of which is an iron clamp holding the base of the rail firmly in position. The weight of the rail helps to hold it in place; and, the pressure of the contact shoe being downward, there is little side strain upon the conductor rail.

*Rails are rated by the weight per yard. It is convenient to remember that the weight per yard is approximately equal numerically to 10 times the cross-section in square inches. A cubic inch of steel weighs about 0.28 pound.

Under-Running Construction. The inverted, or under-running, type of third-rail construction is shown in Figs. 230 and 231. The details of the mechanical and insulating parts are plainly shown. This type of construction is much more successful where severe snowstorms or sleet storms are experienced, as these tend to interfere with the operation of the exposed type of rail. There is also less danger of accident to employes and smaller probability of interruption due to accidentally short-circuiting the rail to the ground.

Bonding. The sections of conductor rail are electrically connected by copper bonds which are riveted or welded to the ends of the abutting rails.

RETURN CIRCUIT

Rail Bonds. The track rails are practically always used as the return circuit, which is at approximately ground potential. It is therefore important that the resistance of these rails be reduced to as low a value as possible. For this purpose the ends of the rails are connected together with copper bonds, making the joint resistance as nearly as possible the same as that of the rail. It is not economical, however, to install sufficient copper to equal the actual rail resistance.

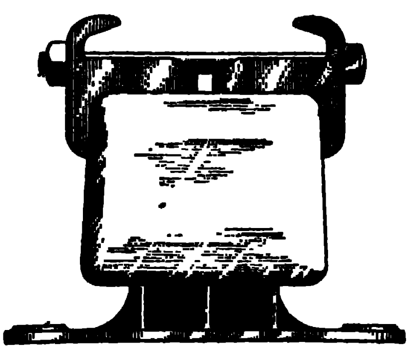


Fig. 229. Third-Rail Insulator
Courtesy of General Electric Company, Schenectady, New York

Size of Bond. To meet electrical requirements, it would be sufficient to connect the rails with the shortest possible bond, thus avoiding any unnecessary cost of copper. The mechanical considerations, however, necessitate much longer bonds in order to provide for the expansion and contraction of the track and to enable it to withstand vibrations due to frequent passage of trains. Various tests have been conducted with different types of bond construction to determine the greatest flexibility and consequently the longest-lived type of construction. These tests indicate that the ribbon conductor will withstand a greater number

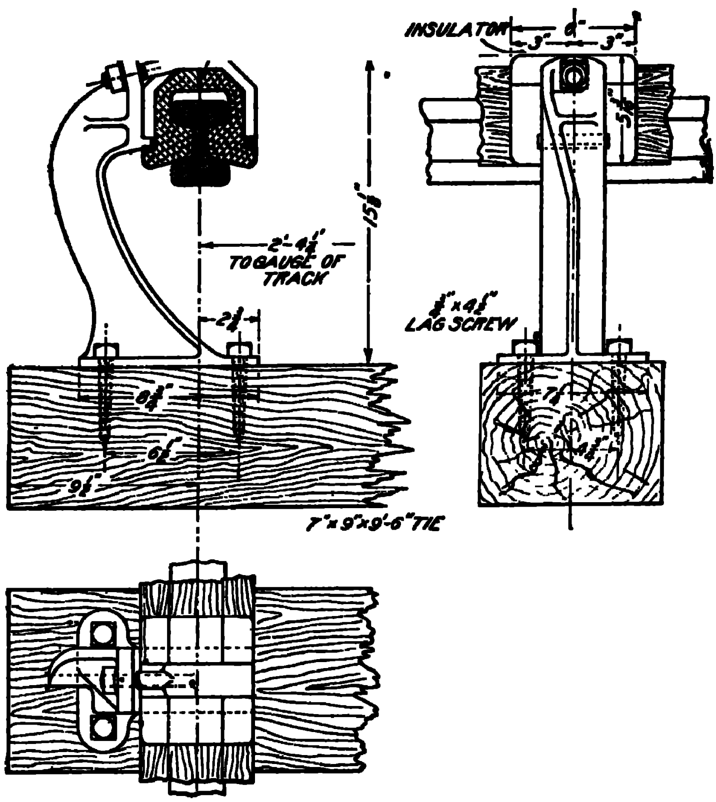


Fig. 230. Details of Insulator and Bracket for Inverted Rail

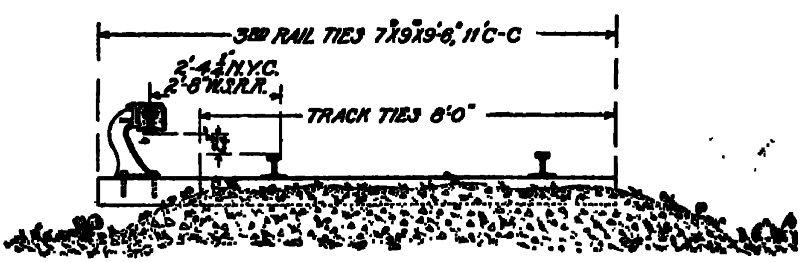


Fig. 231. Inverted-Rail Insulator Mounted on Tie

of vibrations than either the round or pressed cable, for the same length of bond. These tests also indicate that the break in every case starts at the center of the conductor, regardless of the form

Fig. 232. Exposed Bond Spanning Joint Plate of T Rail
Courtesy of General Electric Company, Schenectady, New York

of bond. From these tests it has been determined that tracks carrying heavy traffic should be bonded with conductors not less than 12 inches in length, while for lighter traffic 10-inch bonds are

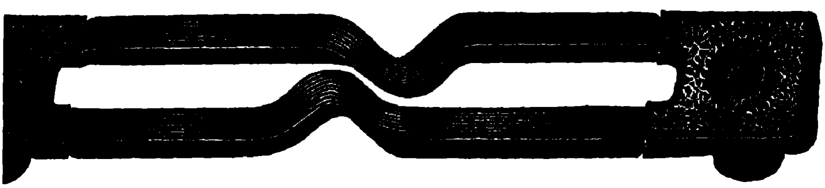


Fig. 233. Ribbon Bond
Courtesy of General Electric Company, Schenectady, New York

sufficient. A good general rule for the size of bond is that the total cross-section of the bonds on the two rails or on the several rails should equal the total cross-section of copper trolley wire and feeder cable.

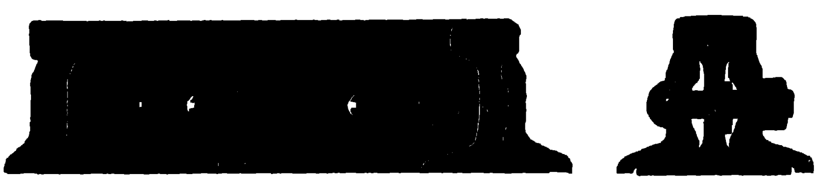


Fig. 234. Compressed Terminal Bond on Web of Rail
Courtesy of General Electric Company, Schenectady, New York

Types. Wherever conditions permit, the bond should be concealed under the joint plate; this protects the bond from mechanical injury or from possible theft. On some types of construction,

however, there is no space available for installing the bond under the joint, and for these cases it is necessary to use an exposed bond, either connecting the rail heads or, as in Fig. 232, extending the entire length of the joint plate. For this purpose both stranded and solid wire bonds are used. The solid bonds are entirely satisfactory when used on rigid construction, such as where steel crossties are set in concrete and the rail is supported by the adjacent pavement.

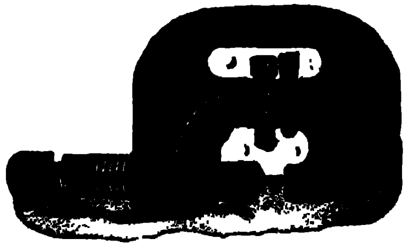


Fig. 235. Double-Screw Rail Bond Compressor

The type of bond most commonly used is constructed with a terminal stud, Figs. 233 and 234, approximately 1 inch in diameter, which is installed by means of a double-screw compressor, Fig. 235, operated by one man with a standard 40-inch wrench. This device is capable of exerting a pressure of 20 tons. After the holes are drilled in the rail, one or more annular grooves are cut in the walls of each hole. A terminal stud fits into each hole and is subjected to such great pressure by the screw that it expands and fills the grooves in the hole. The projecting edges are next riveted down, making a permanent attachment. In Fig. 236 is shown a section of the web of a rail with the stud in place after being put under sufficient pressure to fill the grooves. Care should be taken to avoid the use of oil in drilling the hole, and after the terminal has been forced into place it should be sealed by the application of suitable paint.

Fig. 236. Section through Rail Web and Compressed Terminal Bond after Installation

Another type of terminal is known as the tubular stud, Fig. 237. These bonds are also compressed into the holes by means of a taper punch, which passes through the center of the terminals. Another form of terminal is known as the twin-stud type, Fig. 238. These terminals are hammered into the rail head, completely filling the hole and grooves, Fig. 239, which are made for the purpose

of anchoring the rivet. Soldered rail bonds are also used to a certain limited extent. The installation of a soldered bond requires the greatest care to ensure both electrical and mechanical attachment between the copper and the steel.

Fig. 237. Section of Tubular-Stud Terminal
Courtesy of General Electric Company, Schenectady, New York

Maintenance. In order to maintain the bonding system in good condition, periodical tests must be made to discover defective joints. It is also of great importance to keep the running rail itself in good condition to avoid motion between the ends of the rails, which will tend to loosen the bonds or break the strands.

Fig. 238. Twin-Stud Terminal Bond on Rail Head
Courtesy of General Electric Company, Schenectady, New York

Resistance of Track. The resistance of the return circuit is sometimes much higher than it should be, owing to the poor contact of the bonds. The resistance of rails varies greatly with the proportions of carbon, manganese, and phosphorus. The following figures, however, may be regarded as average values for the rail alone.

Weight per Yard (lb.)	Resistance Single Rail per Mile (ohm)
50	0.095
60	0.079
70	0.063
80	0.059
90	0.053

A single track laid with continuous rails would have one-half the resistance given, since there are two rails in parallel.

A bond may be considered good when the bond and 1 foot of the rail over it have a resistance equal to 5 feet of the solid rail. The theoretically perfect bond, as previously explained,

would be equal in conductivity to the rail, but such a bond would be too expensive.

Example. What is the track resistance of a double-track road 10 miles long, laid with 70-pound 30-foot rails and bonded so that each bond and the foot of rail between its terminals have the same resistance as 5 feet of rail?

As there are four rails in parallel, the resistance per mile is one-fourth of the value given in the tabulation. There is one bond in each rail every 30 feet, and this adds 4 feet of rail as far as the resistance is concerned. The resistance of 1 mile is, therefore, increased in the ratio of 34 to 30. The track resistance is, therefore,

$$R=10\times\frac{34}{30}\times\frac{0.063}{4}=0.178 \text{ ohm}$$

Bond Testing. It is important to test the conductivity of rail bonds from time to time in order to determine if they have deteriorated so as to reduce their conductivity and introduce an unnecessary amount of resistance into the return circuits. One way of doing this is to measure the drop in voltage over a bonded joint as compared with the drop in an equal length of unbroken rail. To do this, an apparatus is employed whereby simultaneous contact will be made bridging 3 or more feet of rail and an equal length of rail including the bonded joint, as shown in Fig. 240, which illustrates the connections of a common form of apparatus where two millivoltmeters are employed to measure the drop in voltage of the bonded and the unbonded rail simultaneously. If the current flowing through the rail due to the operation of the cars were constant, one millivoltmeter might be used, connected first to one circuit and then to the other. The current in the rail, however, fluctuates rapidly, so that two instruments are necessary for rapid work. The resistance of the bonded joint is usually considerably more than that of the unbroken rail, and the millivoltmeter used to bridge the joint consequently need not be so sensitive as that bridging the unbroken rail.

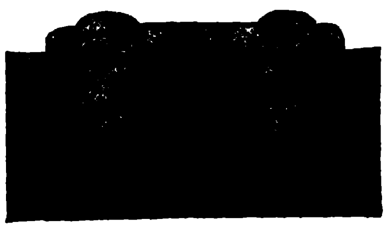


Fig. 239. Section of Twin-Stud Terminal as Forced into Rail Head

In another form of apparatus a telephone receiver is used instead of the millivoltmeter, the resistance of a long unbroken rail being balanced against that of the bonded joint, as in a

Wheatstone bridge, until, upon closing the circuit, these two resistances when balanced give no sound in the telephone receiver.

Bond tests of the kinds described can be made with satisfaction only when a considerable volume of current is flowing through the rails at the time of the test, because the drop in voltage is dependent on the current flowing, and in any event is small. It has sometimes been found necessary or advisable to fit up a testing car equipped with a rheostat which will itself use a large current so as to give a current in the rail large enough to give an appreciable drop of potential across a bonded joint. Some of the latest forms of testing cars carry motor-generators which pass large currents of known values through bonded joints and

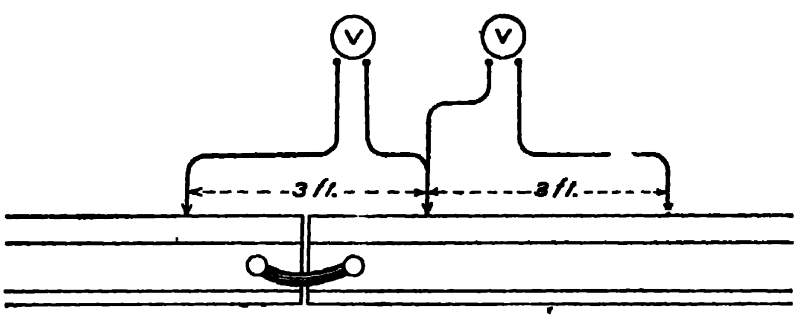


Fig. 240. Common Form of Bonded Joint with Millivoltmeters Attached to Show Voltage Drop

so cause drops across the joints large enough to be easily measured.

Supplementary Return Conductors. On some large roads it is necessary to run additional return feeders from the power house to various points on the system to supplement the conductivity of the rails. Otherwise the track rails near the power house would have to carry all the current, and in some cases there are not enough such lines of track passing the power house to do this properly. Sometimes these feeders are laid underground in troughs, sometimes bare in the ground, and sometimes on overhead pole lines. When the return feeder is laid in the ground, old rails may be used instead of copper or aluminum cables, the rails being thoroughly bonded to give a conductivity nearly equal to that of the unbroken rail.

FEEDER SYSTEMS

Types. There are two general schemes of d.c. feeding in common use. One of these is shown in Fig. 241. Here the trolley wire is continuous and is fed into at different points. The long

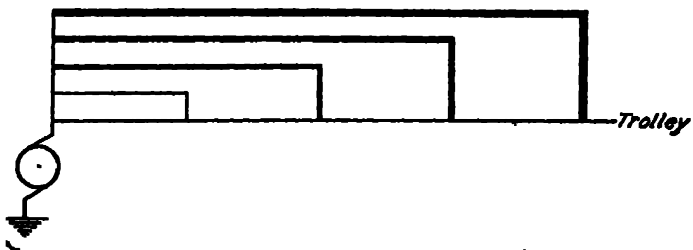


Fig. 241. Diagram of Trolley Feeder System

feeders supplying the more distant portion of the road are larger than those supplying the trolley near by so as to maintain as nearly as is feasible the same voltage the entire length of the line. The plan shown results in a higher voltage near the power station than at distant points, but the distribution of voltage is better than if the heaviest feeders were feeding into the trolley near the power house. In the other plan, Fig. 242, the trolley wire is divided into sections and each is fed through a separate feeder which is of such size as to maintain the same voltage on all the sections with the ordinary load.

Feeder Calculations. In estimating the proper sizes of wire for a feeder system probable loads are assumed at certain points along the line. These will depend on the size and number of cars in operation, grades, and many local conditions.

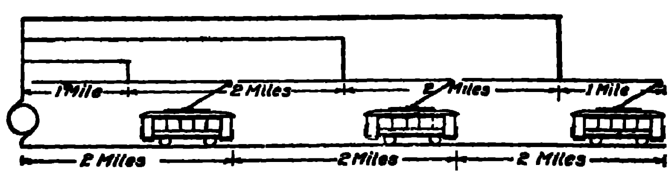


Fig. 242. Feeder System Using Separate Trolley Sections

Example. Assume that three cars are placed, as shown in Fig. 242, each at the end of a feeder section and that each is drawing 50 amperes. The line voltage is 600 and the allowable drop in feeders, trolley, and return circuit is placed at 10 per cent, or 60 volts. The track is single and laid

TABLE VI

Rail-Resistance Data

	End of Section 1	End of Section 2	End of Section 3
Drop in track section, volts	10.72	7.15	3.57
Total drop in track, volts	10.7	17.9	21.5
Drop in trolley wire, volts	20.5	20.5	20.5
Total drop in track and trolley wire, volts	31.2	31.2	31.2
Allowable drop in feeder, volts	28.8	21.6	18.0
Feeder resistance, ohms	0.576	0.432	0.36
Feeder resistance, ohms per mile	0.576	0.144	0.072
Nearest (larger) size of wire from wire tables	0	400000 c.m.	750000 c.m.

with rails weighing 70 pounds to the yard. The trolley wire is No. 00. The lengths of the sections are as given in the illustration.

As the sizes of trolley wire and rails are given, the drops in these must be calculated first, and the remainder of the allowable drop will be that which may occur in the feeder. The current in each trolley wire is 50 amperes and from wire tables a mile of No. 00 wire will cause a drop of 20.5 volts with 50 amperes. The current in the two miles of track nearest the power house is 150 amperes; in the next section, 100 amperes; and in the last section, 50 amperes. The corresponding voltage drops are calculated from these currents and the resistances of the track sections. A 70-pound rail has a resistance of 0.063 ohm per mile, Table VI. As explained before, this may be increased in the proportion of 34:30 to allow for bonding; and as there are two rails in parallel, the rail and bond resistance must be divided by two. The track resistance of each 2-mile section is, therefore, 0.0715 ohm. The drop in the first section (nearest the power house) is 150×0.0715, or 10.72 volts; that in the second section is 100×0.0715, or 7.15 volts; and that in the third section is 50×0.0715, or 3.57 volts. The track drop from the power house in each case is obtained by adding together the individual drops. Hence, the drop to the end of section 1 is 10.7 volts; to the end of section 2, 17.9 volts; and to the end of section 3, 21.5 volts.

As a total drop of 60 volts at each car in the positions shown has been allowed, the allowable drop in each feeder may be obtained by subtracting from 60 volts the calculated drop in trolley and track in each case. Then, by dividing the drop by the corresponding current, the total resistance of each feeder is determined. Dividing this value by the length of the feeder gives the resistance per mile or per thousand feet, and the corresponding size can be read directly from a wire table. After doing this there result the values shown in Table VI.

STRAY EFFECTS OF ELECTRIC-RAILWAY CIRCUITS

Electrolytic Currents. Much has been said about the possibilities of electrolysis of underground metal by the action of

return currents of electric railways, when operated as they usually are with grounded circuits. If electric current is passed through a liquid from one metal electrode to another, electrolysis will take place; that is, metal will be deposited on the negative pole, and the positive pole, or electrode, will be dissolved by becoming oxidized from the action of the oxygen collecting at that pole.

In an electric-railway return circuit there is necessarily a difference of potential between the rails in outlying parts of the system and the rails and other buried pieces of metal located near the power house. The value of this difference of potential depends on the loss of voltage in the return circuit. Thus, suppose there is a drop of 25 volts in the return circuit between a certain point on the system and the power station. There is, therefore, a pressure of 25 volts tending to force the current through the moist earth

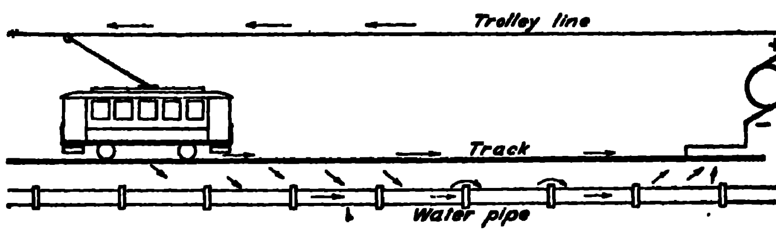


Fig. 243. Diagram Showing Stray Current to Water Pipe

from the rails at distant portions of the line to the rails, water pipes, and other connected metallic bodies located in the earth near the power station. The value of the current that will thus flow to earth in preference to remaining in the rails depends on the relative resistance of the rails, the earth, and the other paths offered to the current to return to the power house.

To take a very simple case, suppose a single-track road, Fig. 243, with a power house at one end and a parallel line of water pipe on the same street passing the power house. If the positive terminals of the generators are connected to the trolley wire, the current passes, as indicated by the arrows, out over the trolley wire through the cars and to the rails. When it has reached the rails it has the choice of two paths back to the power house. One is through the rails and bonding; the other is through the moist earth to the line of water pipe and back to the power

house, leaving the pipe for the rails at the power house. Should the bonding of the rails be very defective, considerable current might pass through the earth to the water pipe.

From the principles of electrolysis, it is seen that the oxidizing action of this flow of current from the rails to the water pipes at the distant portion of the road will tend to destroy the rails but will not harm the water pipe at that point, as it will tend to deposit metal upon it. When, however, the current arrives at the power house, it must in some way leave this water pipe to get back to the rails and so to the negative terminals of the generators. There is thus a chance for corrosion of the water pipe, because at this point it forms the positive electrode, which is the one likely to be oxidized and destroyed. This very simple case is taken merely for illustration. In actual practice the conditions are never so simple as this, for there are various pipes located in the ground in various directions, which complicate matters very much; but it is evident from this simple example that the points at which corrosion of water pipe is to be expected are those at which currents leave the pipe to reach some other conductor.

As an indication of how much current is likely to leave the water pipes at various points, it is customary to measure the voltage between the water pipes and the electric-railway track and rails. When this voltage is high, it does not necessarily mean that a large volume of current is leaving the water pipes at the point where these pipes are several volts positive with reference to the rails; but such voltage readings indicate that if there is a path of sufficiently low resistance through the earth and if the moisture in the earth is sufficiently impregnated with salts or acids, there will be trouble from electrolytic action due to a large flow of current. There is no method of measuring exactly the amount of current leaving a water pipe at any given point, since the pipe is buried in the earth. Voltmeter readings between pipes and rails simply serve to give an indication as to where there is likely to be trouble from electrolysis. The danger to underground pipes and other metallic bodies from electrolysis has been much overestimated by some people, as the trouble can be overcome by proper care and attention to the return circuit. Trouble from electrolysis, however, is sure to occur unless such care is given.

Prevention of Electrolysis. Remedies for electrolysis may be classified under two heads—general and specific. The general remedy is to make the resistance of the circuit through the rails and the supplementary return feeders so low that there will be but little tendency for the current to seek other conductors, such as water and gas pipes and the lead covering of underground cables. This remedy consists of heavy bonding, of ample connections around switches and special work where the bonding is especially liable to injury, and of additional return conductors at points near the power house to supplement the conductivity of the rails. It is important that all rail bonds be tested at intervals of six months to one year in order that defective bonds may be located and renewed, as a few defective bonds can greatly lower the efficiency of an otherwise low-resistance circuit.

The specific remedy for electrolysis, which may be applied to reduce electrolytic action at certain specific points, consists in connecting the water pipe at the point where electrolysis is taking place with the rail or other conductors to which the current is flowing. Thus, for example, if it is found that a large amount of current is leaving a water pipe and flowing to the rails or to the negative return feeders at the power house, the electrolytic action at this point can be stopped by connecting the water pipe with the rails by means of a low-resistance copper wire or cable, thereby short-circuiting the points between which electrolytic action is taking place. There are certain cases in which it is advisable to adopt such a specific remedy. It should be remembered, however, that a low-resistance connection of this kind, while it reduces electrolysis at points near the power house, is an added inducement to the current to enter the water pipes at points distant from the power house. This follows because the resistance of the water-pipe path to the power house is decreased by the introduction of the connection between the water pipe and the negative return feeder at the power house. With the water pipes connected to the return feeders in the vicinity of the power house, the current which flows from the rails to the water pipes at points distant from the power house will cause electrolysis of the rails but not of the water pipes, since the current is passing from the earth to the pipe, the pipe being negative to the earth. In this case the

principal danger is that the high resistance of the joints between the lengths of water pipe will cause current to flow through the earth around each joint (as indicated on some of the joints in Fig. 243) and thus produce electrolytic action at each joint. It is evident, however, that the conditions of the track circuit and bonding must be very bad if current would flow over a line of water pipe, with its high-resistance joints, in sufficient volume to cause electrolysis, in preference to the rail-return circuit, especially since ordinarily the resistance offered to the flow of current over the water pipes back to the power house must include the resistance of the earth between the tracks and the water pipes. It is usually considered inadvisable to connect tracks and water pipes at points distant from the power house, because of the danger of electrolysis at pipe joints.

Inductive Interference. On single-phase railroads some trouble has been experienced from interference with neighboring telephone and telegraph lines, owing to the induced currents caused by the rapid fluctuations in the railway conductor circuit. Serious interference has been caused where the telephone and telegraph circuits were many feet distant from the railway lines. This problem has been carefully studied, and several methods have been employed to reduce the disturbance, but so far it has not been possible to eliminate the inductive effects entirely.

SIGNAL SYSTEMS

Importance of Safety. In the operation of electric railways safety to passengers and equipment is a prime consideration. In the operation of high-speed interurban railways, particularly in the case of single-track roads, there is great danger of collision and damage unless provision is made for giving the train crews reliable information regarding the location of other cars within a short distance and on the same track.

Dispatcher. Cars are operated upon a regular schedule which provides for the safe operation of the road if all cars are strictly on time and if there are no extra or special cars on the line. Special cars are a great source of danger unless their location is known to the crews of all cars which might possibly collide with them.

The duty of the dispatcher in a railway system is to so regulate the movements of the cars that safety will result. He will be assisted by the use of some sort of a graphical time-table or train sheet such as is shown in Fig. 244. This is laid out with the time as the base and the position of the cars as the vertical scale. A diagonal line on the diagram drawn at such an angle as to correspond with the average speed will show at each instant the approximate position of a given car. Any number of regular and special cars can be followed in this way. This graphical time-table can also be made by means of a board supplied with pegs at the beginnings and the ends of the runs and strings connecting

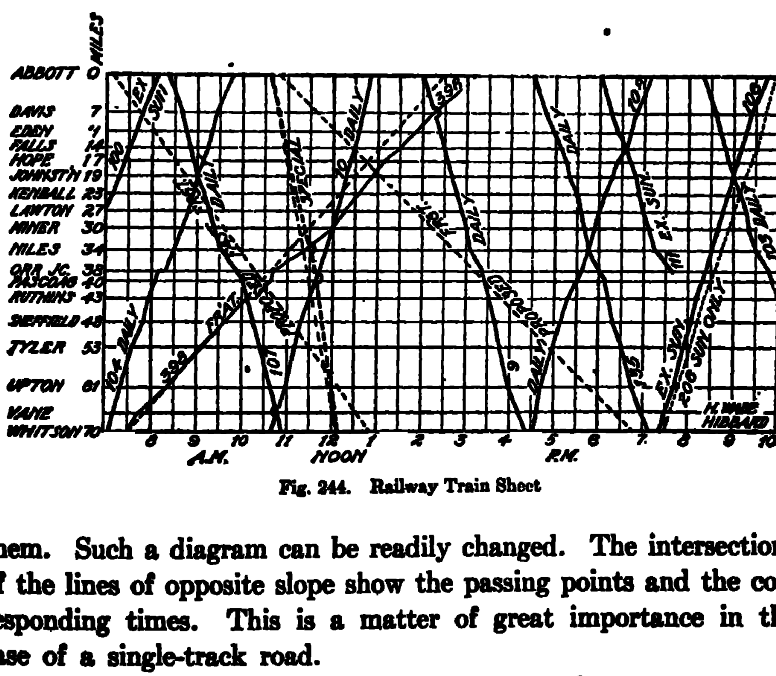


Fig. 244. Railway Train Sheet

them. Such a diagram can be readily changed. The intersections of the lines of opposite slope show the passing points and the corresponding times. This is a matter of great importance in the case of a single-track road.

In addition to the time-table it is necessary for some means to be provided whereby the train crews can get into touch with the dispatcher to learn of special orders, especially if the cars are off schedule. Telephones located at convenient points, such as turnouts, answer this purpose. These allow the crews to call up the dispatcher, but do not permit the dispatcher to call up the crews. With a simple telephone system it is, therefore, necessary to have very strict rules regarding the calling up of the dispatcher in case

of any doubt. In addition to the telephone system it is desirable to have some kind of signals which can be set by the dispatcher

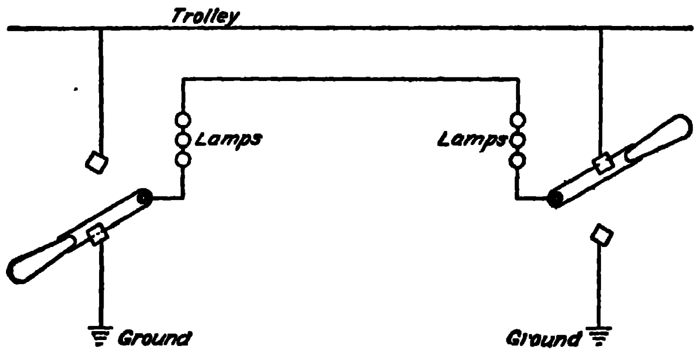


Fig. 245. Hand-Operated Block System

to call the crews to the telephone. Progress is being made in this direction.

Block Signals. For some time the steam railways have used the block plan of operation, the road being divided into signal sections, or blocks. A block is a section protected at the ends by signals indicating whether or not a train is in it. These signals may be set by hand, or they may be automatic, that is, set by the trains. Signals for steam railways have been brought to a high state of perfection. They are very expensive, and the cost of a system such as is used on a steam railway would be prohibitive for electric railways in most parts of the country. At

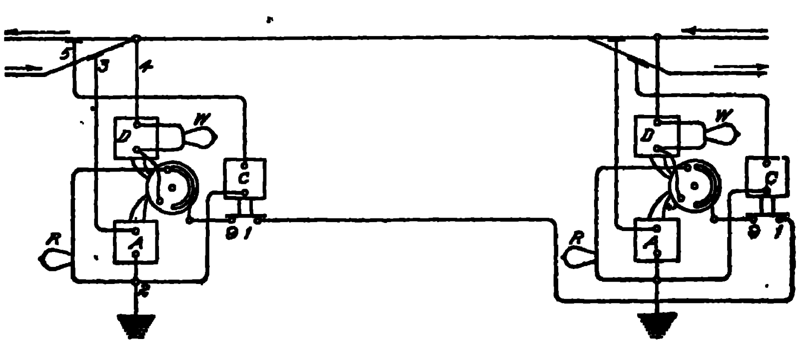


Fig. 246. Diagram of Automatic Block-Signal System

the same time simple block-signal systems are being installed on a number of roads, which indicates that the difficulties met with

in producing a simple, cheap, and effective signal are being overcome. Some of the elements of these systems will be described. It should be remembered, however, that the art is in a state of development at present and practice cannot be considered as standardized.

Hand-Operated. The simplest block signal used by electric roads is a hand-operated one constructed on the principle shown in Fig. 245. At each end of the block a bank of lamps is located to indicate whether or not the block is clear. The lamps are placed in a weatherproof box with a glass window. Red glass is some-

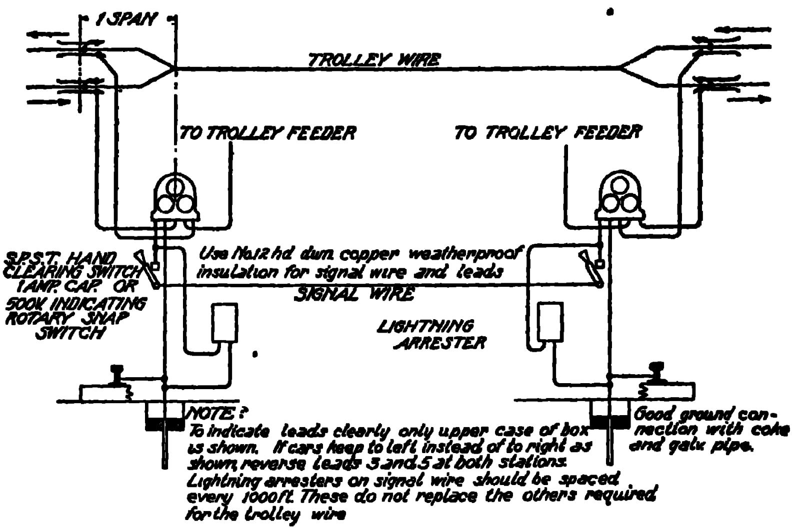


Fig. 247. Diagram of Automatic Block-Signal System

times used to suggest danger. A double-throw switch is connected with the lamps at each terminal of the section, as shown in the illustration. The switches have no central position, the knife blade always making contact with one or the other of the terminals shown. If the lamps are lighted, throwing either one of the switches will put them out, and if they are not burning they will be lighted by throwing either one of the switches. A motorman, on reaching a section of track and finding the lamps not burning, throws the switch. Lamps then burn in each switch box and show that the section is in use. On arriving at the other terminal of

the block the switch is thrown, extinguishing the lights and showing that the block is clear.

Automatic. The crude arrangement just described is only suitable for use on roads with low-speed schedules. It fails to indicate in which direction the car in the block is going and it depends upon the reliability of the train crews in operating it. An automatic system of some kind is, therefore, desirable if it meets the specifications mentioned. One of the simple systems

Fig. 248. Signal Box, White Disc Displayed

Fig. 249. Signal Box with Front Cover Down

which has been developed is shown diagrammatically in Figs. 246 and 247. The essential features of this are as follows: (1) a signal box with red and white lights, located at each end of a block, provided with corresponding red and white semaphore discs; (2) a set of trolley switches by means of which the signal boxes are automatically operated. The signal box is shown in Figs. 248, 249, and 250. The upper part contains the lamps and the red and white "bull's-eyes," and the red and white semaphore discs

which are displayed through the circular opening. In the lower part of the box, submerged in oil, are the relays, or magnets, by which the semaphore discs are moved and the electric circuits controlled. The trolley switch, Figs. 251, 252, and 253, consists of, a light angle-iron frame hung from an insulated hanger and carrying blocks of insulating material on which are mounted the contact strips. The trolley wheel connects these strips with the trolley wire, and from the contact strips wires lead to the relays.


Fig. 250. Box, Showing Operating Mechanism

Before taking up the details, attention is called to the purpose which the device is designed to accomplish. Before a car enters a block the motorman wishes to know if there is a car in the block and, if so, in what direction it is going. This signal system is planned to indicate these two items. When there is no car in the block, there is no light in either signal box and the semaphore discs are down. When a car enters the block a white light and a white disc are displayed at the entering end, and a red light and a red disc at the leaving end. The white light and semaphore show that another car may enter the block but must proceed carefully because there is a car ahead. If on approaching a block a white light is seen, indicating the presence of one or more cars in the block and moving in the same direction as the entering car, the motorman looks for a blinking of the white light as he passes the signal box. This indicates that there is not an excessive number of cars in the block. The way in which these features of operation are secured is shown in Figs. 246 and 247.

In Fig. 246 is shown at each end of the block a revolving switch operated by two magnets A and D. The core of each magnet carries a pawl which works backward and forward on

ratchet wheels, rotating the switch in one direction or the other. The switch carries a semicircular contact strip which makes contact with the terminals shown. Each signal box contains a

Fig. 251. Block Switch, Showing Side Construction

circuit-breaker *C*, its winding being connected in the circuit of the *leaving* trolley switch *5* in the left-hand station. The operation of the apparatus is as follows: With no car in the block, as shown, the signal wire (the lower one) is grounded through the red lamps. Suppose now that a car enters the block from the left; trolley switch *3* is closed and energizes magnet *A*, the armature of which rises and rotates the revolving switch in a clockwise direction.

Fig. 252. Block Switch, Showing Under-Construction

This causes the contact strip to break connection with the upper terminal and to close the connection with the lower one. Current now flows from the trolley wire through wire *4*, through white light *W*, in shunt with which is magnet *D* (which is energized and its core lifted through the revolving switch), through contacts *9* and *1* of the circuit-breaker *C*, through the signal wire and the contacts *9* and *1* of the right-hand circuit-breaker, through the upper contact of the revolving switch, through the right-hand red lamp to ground.

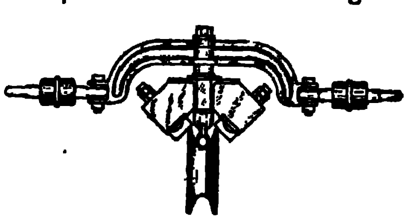


Fig. 253. Section of Block Switch

The trolley wheel of the entering car closes switch *3* for but an instant, after which magnet *A* is de-energized and its armature drops back to the *OFF* position by gravity. The revolving switch, however, remains in its new position.

When the car leaves the right-hand end of the block, its trolley wheel closes the lower trolley switch and energizes the coil

of right-hand circuit-breaker C, which opens the signal-wire circuit, de-energizing magnet D at the left. The core of magnet D drops, and the pawl rotates the revolving switch backward by exactly the same amount that it was previously rotated forward, and the whole apparatus returns to the original condition.

Suppose now that several cars are entering the block in the same direction, one after another. As each car closes switch *3*, the revolving switch is rotated through a small angle, but no change is made in the electrical circuit. As magnet A operates, a resistance (connection not shown) is connected in series with white lamp A, thus causing a flicker which indicates that the switch has operated. After a certain number of cars have entered the block, the revolving switch can rotate no farther and magnet A cannot operate. As the cars successively leave the block, the circuit-breaker opens a corresponding number of times, and the switch is rotated backward to its original position when all the cars have left the block.

The connections for controlling the semaphore discs are not shown. It should be understood that the operation of the lamps and discs is synchronous. The white semaphore is operated by magnet D, and the red one by a magnet in shunt with the red lamp but not shown.

This explanation of the operation of an automatic system is deemed sufficient here. For further details of signaling systems in general the student is referred to the text on "Railway Signaling." A number of electric roads have installed systems which use the rails for conducting the signal current. In d.c. railways alternating signal current is used; in a.c. railways a current of higher frequency than the power current is used for the signals. The short-circuiting of the rails by the wheels and axles operates the signals.

MOTORS AND RUNNING GEAR OF PENNSYLVANIA RAILROAD LOCOMOTIVE USED IN HAULING TRAIN TO AND FROM PENNSYLVANIA TERMINAL, NEW YORK CITY

Motors have rating of 2000-horsepower each. Note side rod construction similar to steam locomotive

Courtesy of Westinghouse Electric and Manufacturing Company

STEAM RAILWAY ELECTRIFICATION

PRINCIPLES OF ELECTRIFICATION

Application of Term. By the term "steam railway electrification" in this discussion is meant the replacement of steam locomotives by electric locomotives or multiple-unit cars, with suitable power supply and feeders for supplying the electricity to the moving locomotives. Many light steam railways and also many elevated systems have been electrified, but in most of these cases the change-over has consisted of the substitution of motor cars for the steam locomotives formerly used, these cars being comparable in the main to what are ordinarily called interurban cars. Since the initial heavy steam railway electrification in 1895 made by the Baltimore and Ohio Railroad at Baltimore, there have been applications of electric locomotives to all kinds of service, including tunnel and terminal work, heavy suburban traffic, main-line traffic, grade sections, and switching yards. Table I gives the principal data of a number of American steam railway electrifications.

Advantages. The advantages of electrical operation are:

(1) Reduction in cost of motive power; in other words, for the same quantity of work the cost of electricity at the wheels of the locomotive is less than the cost of coal on the tender;

(2) Reduction in cost of maintaining locomotives, because a smaller number of units will do the same work and no parts are subjected to the high temperature incident to steam-engine and boiler equipment;

(3) Improvement of tunnel and terminal conditions by elimination of smoke, gas, and cinders;

(4) Elimination of delays due to coaling, taking water, loss of steam in cold weather, etc.

(5) Elimination of nonrevenue trains hauling coal or water to be used as fuel and supplies for steam engines;

(6) Increased tonnage per train;

(7) Increased speed on limiting grades;

(8) Reduction in train-crew hours per ton mile hauled, resulting from (6) and (7);

(9) Greatly increased safety of operation and reduction in track and wheel wear where regeneration is used on divisions including severe grades.

TABLE I

Principal Data on American Steam Railway Electrifications

Road	Miles in Route	Miles of Electrified Single Track	Number of Locomotives	Maximum Grade (per cent)	Date Electrified	Number of Substations	Trolley Voltage	Number of Motor Cars	Third-Rail or Overhead	Reasons for Electrification
Baltimore and Ohio	4	8	10	1.5	1895	1	650 d.c.	0	Third-rail	Tunnels and terminals
Boston and Maine	8	22	7	1.0	1911	2*	11000 a.c.	0	Catenary	Tunnel
Butte, Anaconda and Pacific	30	114	28	2.5	1913	2	2400 d.c.	0	Catenary	Economy
Canadian Northern	10	30	6	0.6	1918	1	2400 d.c.	8	Catenary	Tunnel and terminal
Chicago, Milwaukee and St. Paul—Cascade Mountains	220	300	7	2.2	1919	8	3000 d.c.	0	Catenary	Economy
Chicago, Milwaukee and St. Paul—Rocky Mountains	440	590	44	2.0	1915	14	3000 d.c.	0	Catenary	Economy and limiting grades
Detroit River Tunnel	4.5	26	10	2.0	1909	1	650 d.c.	0	Third-rail	Tunnel
Grand Trunk	3.5	12	3	2.0	1908	0	3300 a.c.	0	Catenary	Tunnel
Great Northern	4	6	4	2.3	1909	1	6600 3-phase	0	Direct cross-catenary	Tunnel
Long Island	100	218	0	0.5	1904	15	675 d.c.	477	Third-rail	Suburban service
New York Central	54	258	73	1.0	1906	9	660 d.c.	221	Third-rail	Terminal and Economy
New York, New Haven and Hartford	79	550	102	1.6	1908	20†	11000 a.c.	27	Catenary	Terminal and economy
Norfolk and Western	30	98	12	2.2	1915	6	11000 a.c.	0	Catenary	Grade sections and tunnel
Pennsylvania—New York	15	98	34	1.5	1911	4	650 d.c.	8	Third-rail	Terminal and tunnels
Pennsylvania—Philadelphia	30	116	0	1.0	1915	6	11000 a.c.	115	Catenary	Terminal
Southern Pacific	118	138	0	0.6	1911	3	1200 d.c.	87	Catenary	Suburban service
West Jersey and Seashore	75	155	0	1.5	1906	8	700 d.c.	109	Third-rail	Economy

* Switching houses
† Autotransformer

The reasons for the electrification of the railroads now using electric locomotives have been: first, improvement of tunnel and terminal service; second, compulsory legislation; third, increased track capacity on grade sections; and fourth, actual savings in the cost of transportation.

An electric locomotive coupled to the Twentieth Century Limited is illustrated in Fig. 1, and an electric locomotive used by the Great Northern Railway in Fig. 2.

Systems Used. In the United States there are three commercialized systems used for heavy traffic: direct current at 600, 1200, 1500, 2400, and 3000 volts; alternating current, single phase, 25 cycles; and alternating current, three phase, 25 cycles.

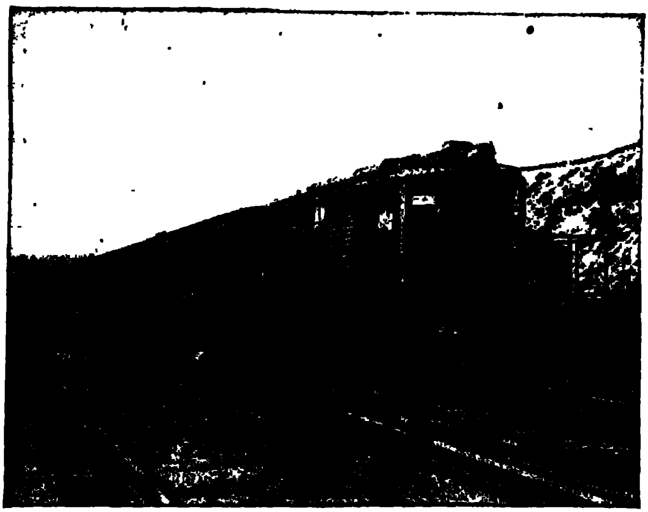


Fig. 1. General Electric 130-Ton, 600-Volt Direct-Current Gearless Locomotive Hauling Twentieth Century Limited on Electrified Division of New York Central Railroad

Direct-Current System. The d.c. system has been used for many years on street railways and elevated lines and employs a straight series d.c. motor, which has characteristics eminently suited to traction work. In steam railway electrification the same general scheme is commonly employed in the arrangement of motors as on the well-tried street-railway systems; that is, the motor is geared to the driving wheels and is compactly built so as to be carried on the truck frame.

Fig. 2. Great Northern Cascade Tunnel Locomotive

The direct current supply is not adapted to long transmission, and it is customary to use three-phase alternating current power generation, either 25 or 60 cycles, with transmission at high voltage and synchronous converters or motor-generator sets in suitably located substations. The d.c. distribution can be either by third-rail or by overhead construction. Because of the standard frequency and three-phase voltage employed, it is frequently possible to purchase power and thereby avoid the heavy first cost of installing a special generating station.

Single-Phase Alternating Current. The single-phase a.c. system comprises a high-tension single-phase transmission system from which power is usually stepped down to 3300, 6600, or 11,000 volts for the trolley and again lowered on the locomotives to the motor voltage. The control of the motor speed is secured by taps on the transformer winding, which gradually step up the voltage until full speed is reached. The characteristics of the motor are similar, in general, to those of the d.c. motor, but more care must be taken in the magnetic structure to avoid eddy-current and hysteresis losses due to the alternating flux. The motor used for this work is of necessity somewhat heavier and larger for the same horsepower than a d.c. motor. For this reason, the equipment requires heavier trucks, and the locomotive complete is of greater weight than a d.c. locomotive of the same hauling capacity. The overhead construction requires careful insulation and maintenance, and provision must be made to minimize the interference with neighboring telephone and telegraph lines caused by the inductive and electromagnetic effects of the alternating current taken by the locomotives. A variation of the straight single-phase scheme has been successfully used by the Norfolk and Western Railway, consisting of a single-phase distribution with a single-phase to polyphase transformation on the locomotive, thus avoiding the use of commutator motors by the substitution of three-phase induction motors.

Three-Phase Alternating Current. The three-phase a.c. system employs a locomotive with a simple form of induction motor adapted for mounting on trucks in a way similar to that employed with d.c. motors. It is the lightest of all the traction motors for its horsepower output. However, it has constant-speed character-

istics which render it inefficient during the period of acceleration and cause it to take large drafts of current on grades in order to maintain approximately synchronous speed. Since two overhead conductors and two sets of collecting devices are required, as well as resistors for the rotor circuit, step-down transformers, etc., this system is not seriously advocated in the United States.

Conclusions. There has been but one installation employing three-phase distribution and locomotives in this country, partly because of the objections raised by steam-railroad men to the double overhead construction, which is necessarily complicated and difficult to maintain, especially in switching yards. It is probable, therefore, that electrification will be confined to the use of high-voltage direct current on the one hand and single-phase alternating current, either with commutator motors or with three-phase induction motors, on the other. In sections of the country where the standard frequency is 60 cycles and where it is more economical to purchase power than to build a special power plant, the d.c. system has a slight advantage owing to the necessity for frequency-changing sets in the case of single-phase distribution, which offsets the cost of the motor-generator sets for converting the alternating current supplied to direct current in the d.c. system.

The general tendency is toward the fixing of 60 cycles as the standard frequency in order to enable the various power users, including lighting, industrial, and railway companies, to obtain power from the same large system, thus obtaining the highest possible load factor.

The single-phase system has been successfully used in several electrifications, and there is no doubt but that either direct current or single-phase can easily be proved superior to steam-locomotive haulage. The theoretical simplicity of the single-phase system, in which one side of the generator is connected to the ground and the other to the trolley wire, has not been found entirely satisfactory in actual service owing to the effect of short-circuit surges on the power station and of inductive effects on neighboring telephone and telegraph circuits.

Factors Affecting Electrification. For many years electricity has been resorted to by steam railroads for tunnel and terminal work under conditions where the use of steam locomotives was

TABLE II

Costs of Electrification of Butte, Anaconda and Pacific Railway Classified in Accordance with Interstate Commerce Regulations

Account No. 1.	Engineering and superintendence (including general preliminary report)	$ 10937.15
Account No. 12.	Roadway tools (used for construction 19 and 22)	3851.74
Account No. 16.	Crossings, fences, guards, and signs, mostly for signs	234.08
Account No. 17.	Interlocking and signal apparatus, new system required account of electrification	22367.62
Account No. 19.	Poles and fixtures (approximately 91 miles track)	135263.98
Account No. 22.	Distribution system (approximately 91 miles track wired)	357009.45
Account No. 25.	Substation building (existing building used)	191.15
Account No. 31. Account No. 36.	Electrical equipment (five 1000-kilowatt motor-generator sets and 17 locomotive units)	671764.78
Account No. 41.	Interest	9975.80
	Total	$1211595.75

extremely objectionable if not impossible. Consideration is now being given to a large number of cases where roads have reached the limit of their capacity with steam engines and must either build additional track or make grade reductions at a heavy expense. By electrification it is possible to practically double the capacity of a single-track road over severe grades because of the higher operating speed and the greater hauling power of the electric locomotive.

The principal data necessary for the study of a proposed electrification are: (1) condensed profile; (2) map showing curvature; (3) number of trains per day; and gross weight—freight and passenger; (4) schedule speed and number of stops; and (5) mechanical details such as weight of rail, number and location of sidings, etc.

From a study of the foregoing data the electrification engineer can determine the number and size of locomotives needed, the amount of energy consumed in handling the traffic, and the size and location of substations. A study of limiting grades makes it possible to calculate the amount of feeder copper required, and from the substation load assumed a close approximation of the capacity of the power station can be made.

In order to give a general idea of the factors entering into the cost of an electrification the figures given in Table II may be studied. These figures cover the cost of electrifying 90 miles of track, including 30 main-line route miles of the Butte, Anaconda and Pacific Railway. Since this project was completed in 1913, the cost figures are on a pre-war basis.

It will be noted that no expenditure was made for power-station or substation buildings, since power is purchased and transformed in the power company's substations.

Profile. The detail profile of a railroad, as prepared by the company's engineer, shows every change of grade and usually cuts and fills. For determining the size of electric locomotive necessary, a profile with much less detail is entirely satisfactory. This should show the maximum grade between any two points plotted

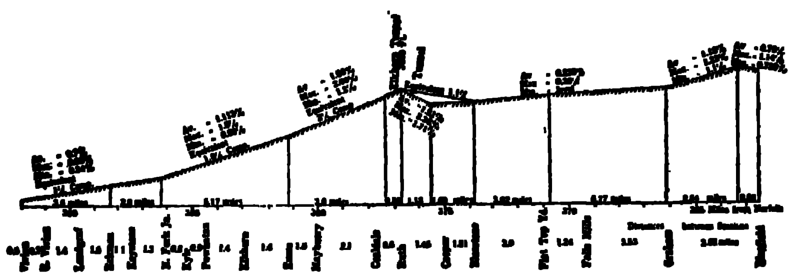


Fig. 3. Profile of Electric Zone of Norfolk and Western Railroad

and the average grade for the same distance. If the grades shown are limiting, that is, such as to limit the weight of train which can be hauled, the exact length should be shown.

In designing a locomotive enough weight must be carried on the driving axles to start a train of the specified weight on the maximum grade without reaching the slipping point of the wheels. The size of the motors is determined by the amount of power required on the limiting grade with a train of the specified weight. The length of this grade affects the heating of the motors, which will deliver a certain horsepower for one hour or a somewhat smaller horsepower continuously. A profile of the electric zone of the Norfolk and Western Railway is given in Fig. 3. The student will note that the limiting grade is about four miles of 2 per cent compensated with an average of 1.66 per cent.

Coefficient of Traction. Electric locomotives are usually rated in terms of weight on the driving axles, tractive effort at the one-hour rating of the motors with the corresponding speed, and, in recent types, the tractive effort at the continuous rating of the motors, also with the corresponding speed. By obtaining the ratio of the tractive effort to the total weight on the drivers, the coefficient of traction can be found. It will be seen that this coefficient is much lower for passenger locomotives than for freight units. This is owing to the fact that in designing it is necessary to allow a larger reserve for starting heavy passenger trains as they start at a higher rate of acceleration than is employed with freight trains. The maximum possible coefficient of traction is limited by the slipping point of the wheels, which, with ordinary rail conditions, occurs at some point between 25 and 30 per cent of the weight on the drivers. By the use of sand on a clean dry rail a much higher coefficient of traction can be obtained for short periods. This figure is not dependent upon the capacity of the motor equipment, but upon the weight of the locomotive which is available for traction on the driving wheels. Thirty per cent of this weight is sometimes used as the maximum tractive effort which a locomotive can exert for a short period.

Curve Compensation. It is standard practice for most steam railways to compensate limiting grades on their system for increased friction due to curvature; for example, if a section of track is laid out so that the grade is 2 per cent "fully compensated," this means that a reduction in the actual grade has been made on the curved portions so that the effective resistance to the passage of the train up grade corresponds to that obtained on a straight track with a grade of 2 feet in each hundred. This means that the actual difference in elevation between two points 1000 feet apart on a 2 per cent grade, instead of being 20 feet, as would be the case on a tangent track, is somewhat less than 20 feet, depending upon the amount of curvature. This matter is of some importance in connection with electrification problems, since the amount of regeneration possible is dependent upon the difference in elevation. The amount of regenerated current which can be sent back to the line is thus somewhat smaller than would be the case were the grades not compensated for curvature. This amount is still

further reduced by the allowance which must be made for curve resistance, which is acting against the motion of the train. The allowance for curve compensation most commonly used is 0.04 per cent per degree of curvature, which corresponds to 0.8 pound per ton per degree of curvature for each per cent grade.

Curve Resistance. On most steam railways there are standing orders to engine drivers limiting the speed downhill on sections where there are severe grades, especially where there are curves.

Fig. 4. Overhead Construction at Ten Degree Curve

In calculating the amount of energy necessary to pull a train over the line an allowance must be made for curve friction due to the flanges of the cars pulling against the inside rail. A curve on which such an allowance must be made is shown in Fig. 4.

Total Resistance. The following items make up the total resistance to the movement of the train which must be overcome by the tractive force of the locomotive: (1) train resistance, 4 to 12 pounds per ton, depending on weights of individual cars and running speed; (2) grade resistance, 20 pounds per ton for each

TABLE III

Weight of Trailing Train

Grade (per cent)	Starting	Running
0.5	11.5× locomotive weight	24.0× locomotive weight
1.0	9.0× locomotive weight	15.7× locomotive weight
2.0	6.1× locomotive weight	9.0× locomotive weight
3.0	4.5× locomotive weight	6.1× locomotive weight

per cent of grade; and (3) curve resistance, 0.8 pound per ton per degree of curvature.

Example. A 1500-ton trailing freight train is to be hauled over a 2 per cent fully compensated grade. What is the total resistance to be overcome? The total train weight is 1500 tons plus the weight of the locomotive, or 1750 tons. The resistance may be tabulated as follows:

Train resistance, 1750×6	10500 pounds
Grade resistance, 1750×40	70000 pounds
Curve resistance not included because of compensation	
Total	80500 pounds

Ans. 80500 lb.

Train Weight. The student will note that the assumed weight of the locomotive is included in the train weight. There are many other factors which the experienced engineer will consider in making his estimate, but for the present we are only interested in the general problem. In Table III is given the weight of trailing train that a locomotive can start on given grades or can haul on the same grade with a running start. These figures are based upon weight on the drivers and do not take into consideration the heating of the motors. The train friction is assumed to be 10 pounds per ton; the acceleration is 20 pounds per ton; and the coefficient of adhesion is 25 per cent.

Energy Required. The energy required to haul an electric train over the line is usually expressed in watt hours per ton mile. This value varies, depending upon the character of the service. For freight trains in main-line service 40 watt hours per ton mile is a good value. For subway and elevated trains making frequent stops and accelerating a large part of the time, this figure runs as high as 170 watt hours.

Example. Find the total energy consumed by a 1500-ton freight train being drawn by a 280-ton locomotive over a division 100 miles long, assuming 40 watt hours per ton mile.

$$\text{Energy} = (1500+280) \times 100 \times 40 = 7\,120\,000 \text{ watt hours}$$

$$\text{Kilowatt hours} = \frac{7\,120\,000}{1000} = 7120$$

Ans. 7120 kw. hrs.

Electric Locomotives. *General Characteristics.* In general, the principles employed in the construction of electric locomotives are not essentially different from those used for ordinary electric cars. For steam railway electrification all locomotives carry two or more double trucks, and the most common construction consists of geared motors mounted on the truck frame with a suitable steel cab (in place of the passenger car body), which is occupied by the various parts of the control apparatus. The motors are of necessity more powerful than are used on trolley cars, and the weight of the locomotive is greater in order to obtain pulling power without causing the wheels to slip.

Steeple-Cab Construction. The type of electric locomotive most successfully used for light railway work consists of two swivel trucks carrying a platform with a cab in the center and sloping housings over each end to protect the control apparatus, Fig. 5. Large numbers of these locomotives weighing from 30 to 60 tons are in operation on light railways for hauling small freight trains and doing light switching. The steeple-cab type of construction has also been adopted for heavier units like the Baltimore and Ohio 90-ton locomotives, the Detroit River Tunnel 120-ton locomotives, and the New York, New Haven and Hartford switchers weighing 80 tons each. The general features of this type of locomotive are shown in Fig. 6, which consists of a plan and elevation with the location of the apparatus indicated. The cab, being located in the center of the locomotive, is conveniently arranged for the driver, who sits in one of the seats located at the right-hand side of the cab. From this seat the motorman can reach the master controller, air-brake valves, main switch, and other apparatus necessary for operating the locomotive. He can also see the air gage and the electrical instruments. The air compressors are located in the center of the cab, and the air-brake reservoirs, resistance grids, control contactors, reverser,

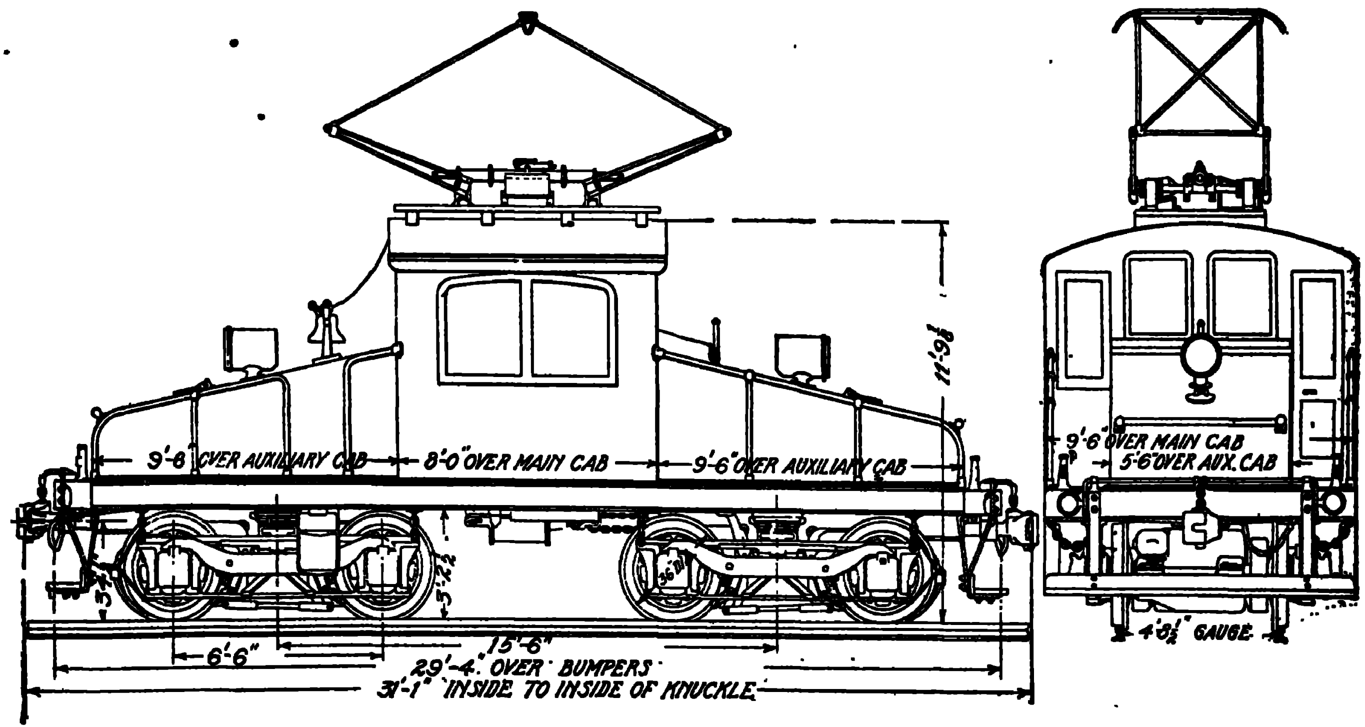


Fig. 5. Side and End View of Typical Light Electric Locomotive

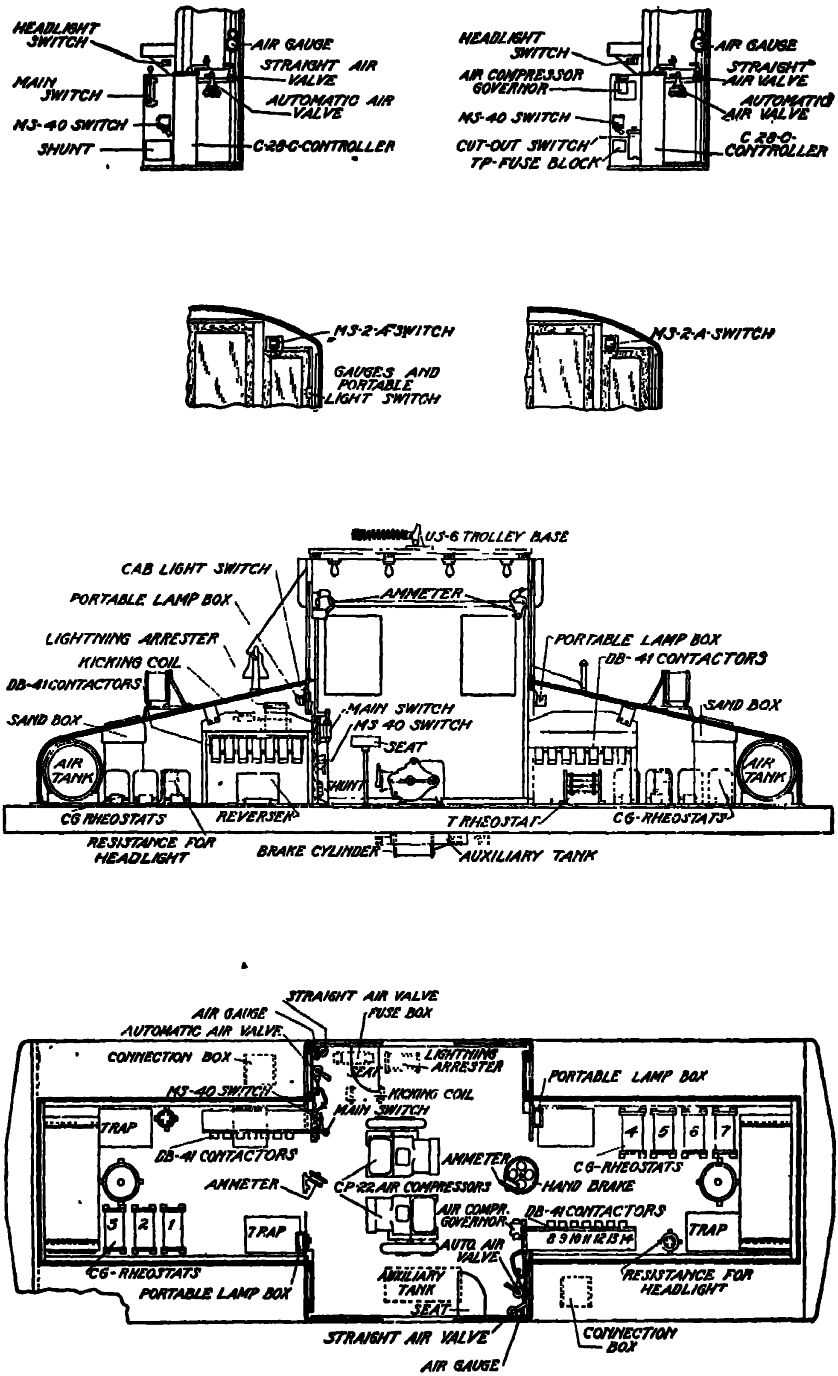


Fig. 6, Sectional Elevation and Plan of Typical Heavy Electric Locomotive

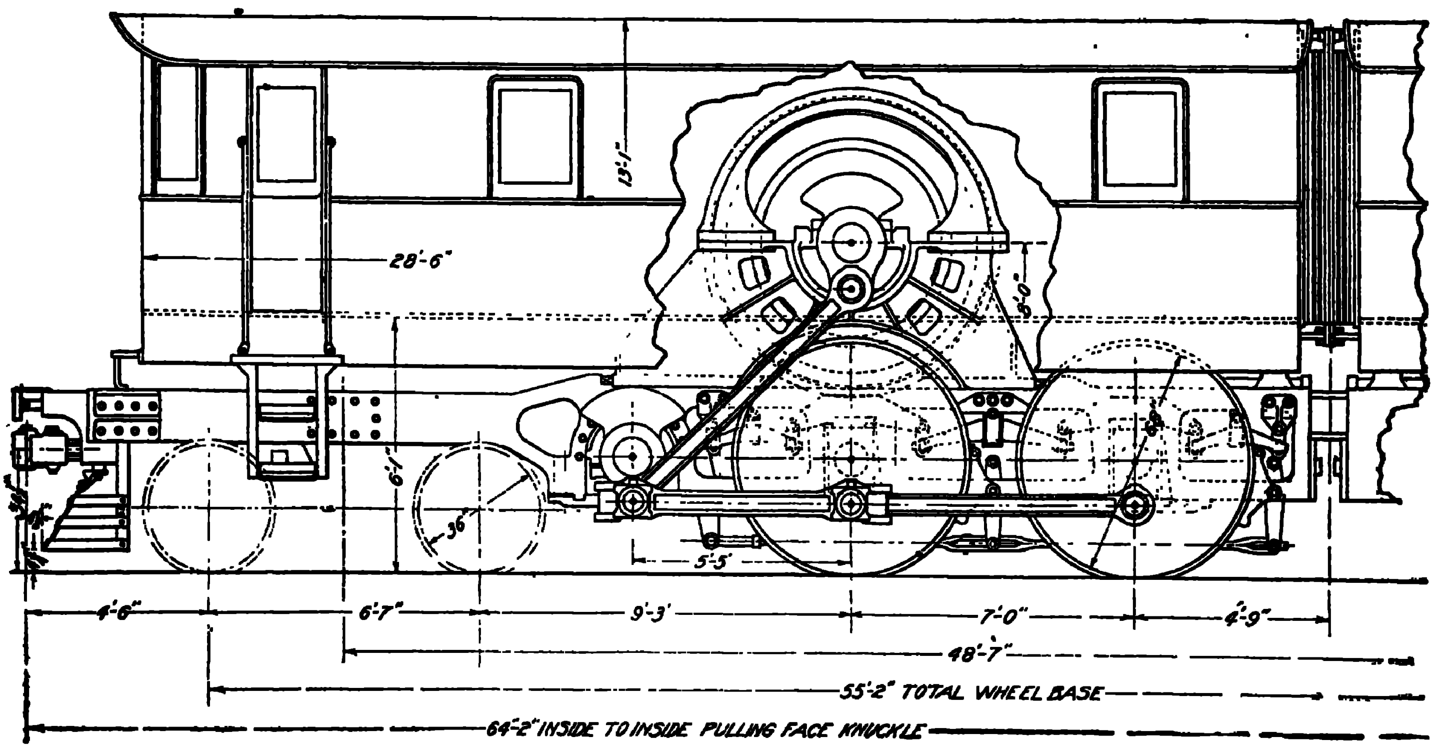


Fig. 7. Part Section, Showing Transmission, and Elevation of One Unit of Pennsylvania Locomotive

etc., are installed under the hood at each end. These portions of the equipment perform the same duties as on ordinary trolley cars, where they are installed underneath the platform in order to secure space for passengers within the car. Where this space is not required for passengers, as in a locomotive, the equipment is much more easily inspected and is better protected when located in the cab.

Other Types of Construction. For heavy main-line traffic it has been necessary to deviate from this type of construction to a certain extent, and in the larger types the square box cab is most frequently used.

In a.c. types and in one case on d.c. locomotives (Pennsylvania Railroad) it has been necessary to adopt a somewhat different method of drive, Fig. 7, because the motors are too large to be mounted on the axles. Most of these types of construction may be regarded as special for their particular service and are described under the various installations.

TYPICAL INSTALLATIONS

In order to obtain a general idea of the character of some of the most important steam railway electrifications now running, brief descriptions of some of these roads with especial reference to electric locomotives, substations, and overhead construction are given.

NEW YORK CENTRAL RAILROAD

(600 Volts Direct Current)

General Data. The New York Central Railroad was electrified in 1906 from the Grand Central terminal north to Harmon on the main line, a distance of 34 miles, and to North White Plains on the Harlem division, a distance of 24 miles. All the traffic over this section is passenger service, and the equipment installed includes high-speed passenger locomotives and multiple-unit cars for the suburban service. The 600-volt d.c. system is used with an under-running third rail for the low-voltage distribution. A train on the main line is shown in Fig. 1.

Locomotives. The electric locomotives are all of the gearless type, capable of operating at speeds as high as 80 miles per hour. The first forty-seven locomotives were constructed with four

bipolar gearless motors located under the central part of the cab and a two-axle guiding truck under each end to ensure good tracking qualities at high speeds. The arrangement of the motor

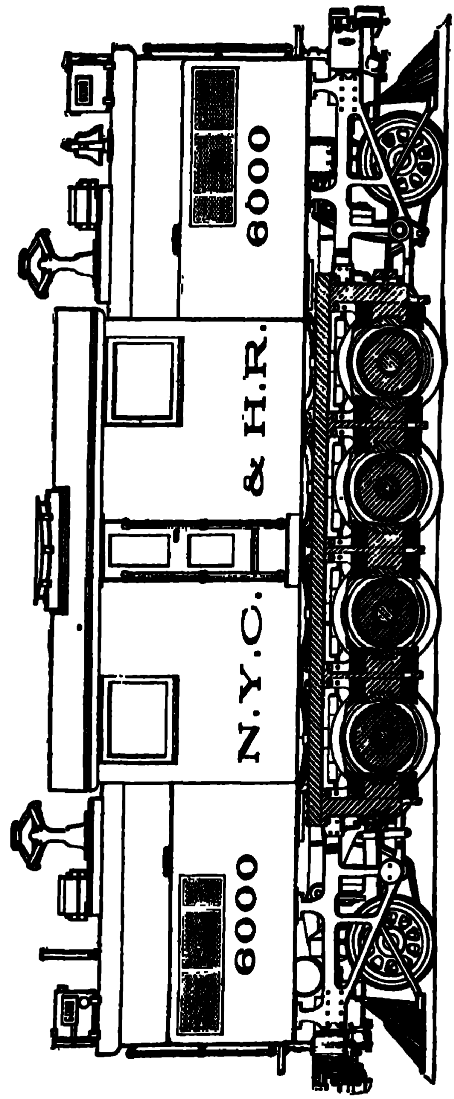


Fig. 8. New York Central Locomotive in Elevation and Part Section

armatures and field pieces is shown in Fig. 8. The armature of the motor is rigidly mounted on the driving axle, and the field structure forms a part of the spring-supported truck frame. The

TABLE IV
Data on Principal Electric Locomotives

Railroad Company	Service	Total Weight (lb)	Weight on Drivers (lb)	Weight per Driving Axle (lb)	At 1-Hour Rating: Tractive Effort	At 1-Hour Rating: Speed (m p.h)	At 1-Hour Rating: Total Horsepower	Tractive Effort for Starting—30 per cent Traction Coefficient	Diameter Driving Wheels (in.)	Gear Ratio	Length Over All (ft. and in.)	Height Over Cab (ft. and in.)	Manufacturer
Baltimore and Ohio	Frt.	200000*	200000	50000	25000	16 4	1120	60000	50	3 25	39–6	12–4	General Electric Co.
Boston and Maine	Frt and Pass	260000	200000	50000	23500	24 2	1510	60000	63	4 14	48–5	12–5	Westinghouse Electric and Manufacturing Co.
Butte, Anaconda and Pacific	Frt.	160000	160000	40000	30600	15 4	1090	48000	[illegible]	4 83	37–4	12–10	General Electric Co.
Butte, Anaconda and Pacific	Pass.	160000	160000	40000	20200	23 4	1090	48000	46	3 2	37–4	12–10	General Electric Co.
Chicago, Milwaukee and St Paul	Frt	576000	450000	56250	84500	15.25	3440	135000	52	4 55	112–0	14–11	General Electric Co.
Chicago, Milwaukee and St. Paul	Pass.	602000	475500	59437	45200	28 5	3440	142650	52	2 45	112–0	14–11	General Electric Co
Chicago, Milwaukee and St Paul	Pass.	532000	330000	55000	49000*	24 5*	3200*	99000	68	3 65	88–7	14–6	Westinghouse Electric and Manufacturing Co.
Chicago, Milwaukee and St Paul	Pass.	530000	458000	38166	46000	26 4	3240	137400	44	Gearless	76–0	14–10	General Electric Co.
Chicago, Milwaukee and St Paul	Switch	140000	140000	35000	18400	12 0	542	42000	40	3 76	41–5	14–3	General Electric Co.
Grand Trunk	Frt.	270000	270000	45000	32210	10 8	1500	81000	62	5 31	55–5	13–0	Westinghouse Electric and Manufacturing Co.
Great Northern	Frt.	230000	230000	57500	38000	15 0	1500	69000	60	4 25	44–2	14–2	General Electric Co.
Michigan Central	Frt	240000	240000	60000	34000	12 3	1120	72000	48	4 37	39–6	12–4	General Electric Co.
New York Central	Pass	230000	[illegible]	35500	21500	37 5	2200	42600	44	Gearless	43–0	13–10	General Electric Co.
New York Central	Pass.	250000	250000	31250	20400	48 5	2640	75000	36	Gearless	56–10	15–1	General Electric Co.
New York, New Haven and Hartford	Pass	220000	169000	42250	9700	54 5	1410	50700	62	Gearless	37–6	12–3	Westinghouse Electric and Manufacturing Co.
New York, New Haven and Hartford	Frt.	220000	165000	41250	17700	36 3	1700	49500	63	4 18	50–0	12–6	Westinghouse Electric and Manufacturing Co.
New York, New Haven and Hartford	Pass	362000	246000	41000	21000	35 0	2550	73800	63	3 22	69–0	12–5	Westinghouse Electric and Manufacturing Co.
New York, New Haven and Hartford	Switch	159200	159200	39800	23200	12 2	750	47760	63	6.32	37–6	12–5	Westinghouse Electric and Manufacturing Co.
Norfolk and Western	Frt.	540000	448000	56000	87000 / 44000	14 2 / 28 3	3280	134400	62	4 72	105–8	13–5	Westinghouse Electric and Manufacturing Co.
Pennsylvania	Pass.	312000	205000	51250	21000	44.5	2500	61500	72	Gearless side rod	64–11	12–8	Westinghouse Electric and Manufacturing Co.

* Continuous rating tractive effort slightly higher and speed lower than for 1-hour rating.

possibility of the armature coming in contact with the pole pieces is prevented by the use of a large air gap and flat pole pieces, Figs. 9 and 10. After the electrification was completed, additional

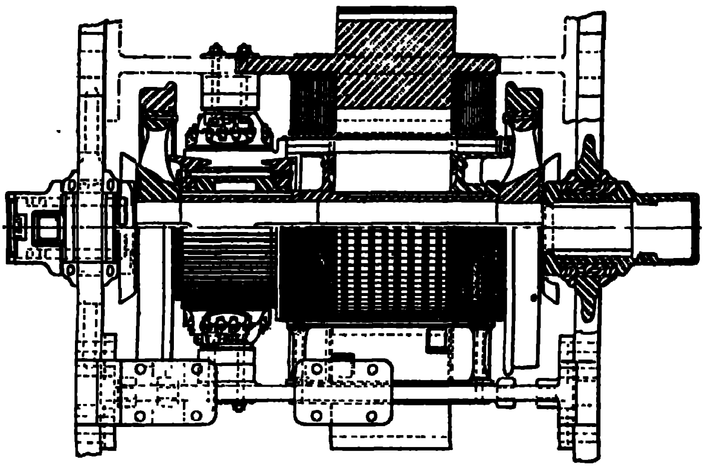


Fig. 9. Section of Locomotive Motor

locomotives were necessary, and twenty-six units were purchased, each equipped with eight bipolar gearless motors with a somewhat larger total horsepower. With this type of locomotive all the axles are driving axles, the front and rear trucks acting as

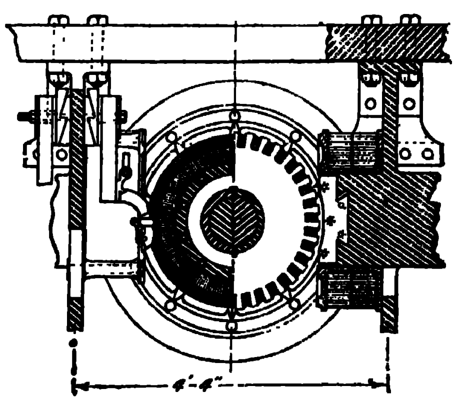


Fig. 10. End Section of New York Central Motor

guides although each carries two driving motors, Fig. 11. Table IV gives data covering this and other types of locomotives. The control equipment is of the multiple-unit type and is similar to

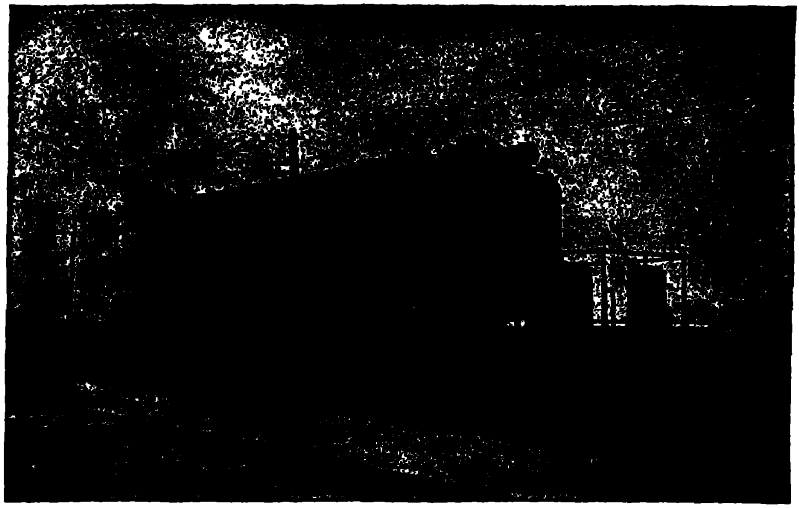


Fig. 11. New York Central Electric Locomotive
Courtesy of General Electric Company, Schenectady, New York

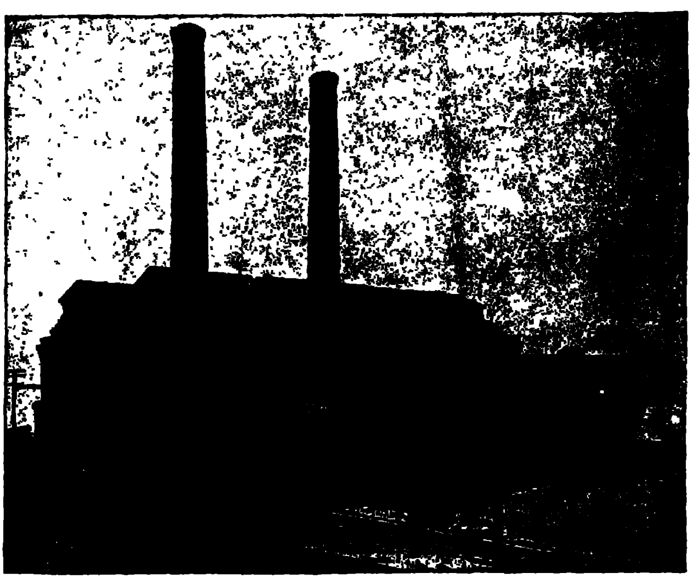


Fig. 12. Power Station on New York Central Railroad
Courtesy of General Electric Company, Schenectady, New York

that used on heavy electric cars, but the contactors are constructed for much heavier service, since the rated current of the complete locomotive is nearly 4000 amperes. These locomotives have three running positions: (1) four motors in series; (2) two motors in series, two in parallel; (3) all motors in parallel.

Substations. There are nine substations located approximately 6 miles apart, having a total of 44,500 kilowatts in synchronous converters changing the three-phase current to direct current.

Power Stations. In order to ensure continuity of power supply, two stations, Fig. 12, were constructed, each of 20,000 kilo-

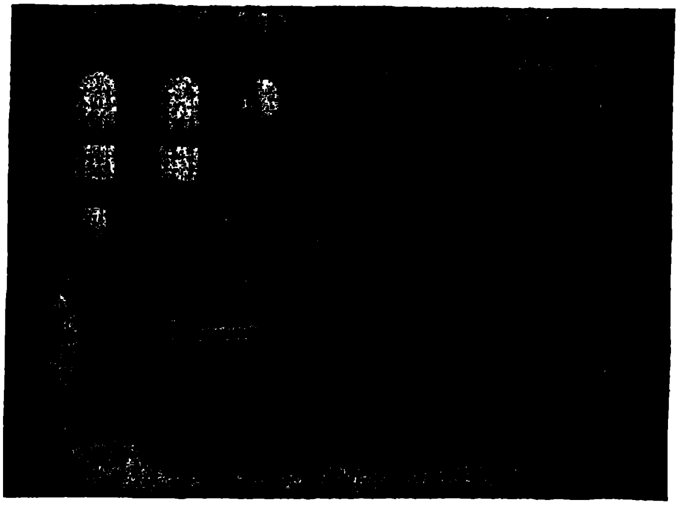


Fig. 13. Interior of Power Station Shown in Fig. 12
Courtesy of General Electric Company, Schenectady, New York

watts capacity and each capable of operating the entire road. Since the traffic has increased, it has been necessary to operate both stations during certain parts of the day, and recently a 20,000-kilowatt unit, Fig. 13, has been installed in the Port Morris station in order to obtain the improved efficiencies shown by up-to-date turbine construction.

Third-Rail Conductor. The 600-volt distribution is made through an inverted double-T type of rail, supported on cast-iron brackets insulated by means of porcelain insulators. This type of construction is described in "Electric Railways," Part III, under "Third-Rail Construction."

PENNSYLVANIA RAILROAD—PAOLI AND CHESTNUT HILL DIVISIONS

(11000 Volts Single Phase)

Increase of Terminal Capacity by Electrification. One of the most important electrifications in recent years is the suburban section of the Pennsylvania Railroad at Philadelphia. Under steam operation the capacity of the Philadelphia station was limited, and in order to increase the train service, it became necessary either to acquire additional real estate and put down new tracks or to resort to electrification. The traffic was, to a large extent, made up of suburban trains, and these have been replaced by multiple-unit equipments. In the case of a steam train the engine hauls the train into the station, and, after the passengers have alighted, must back the train out into the yard, run to the turntable, turn around, and back the train into the station again for the next trip. With the multiple-unit train capable of operating in either direction, the train is immediately ready for departure as soon as the passengers have alighted. The number of train movements at the terminal is thus reduced to less than one-half those required by steam operations, and the capacity of the available tracks is increased in somewhat the same proportion.

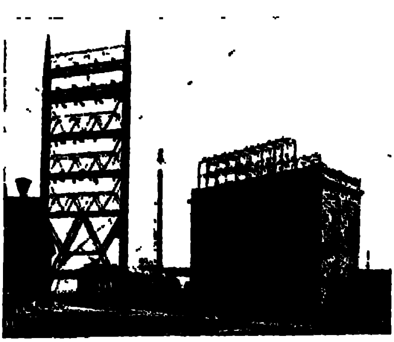


Fig 14. Electric Substation

General Data. The electric zone extends from Broad Street station to Paoli, a distance of 20 miles, with four tracks, and to Chestnut Hill, a distance of 12 miles, with two tracks. There are sixteen station tracks, which are approached by six main-line and three yard tracks. The present suburban service includes about forty-three trains each way per day on the main line and a somewhat smaller number on the Chestnut Hill division.

Power Supply. All power for the operation of electric trains is purchased from the Philadelphia Electric Company and delivered at one of the railway company's substations, Fig. 14, by means of

underground cables transmitting at 13,200 volts, single phase. At this substation the voltage is raised to 44,000 volts and transmitted by duplicate single-phase circuits to the step-down stations. In order to compensate for the unbalancing of the single-phase load, phase-converter sets have been installed in the power company's station; these sets also correct for the relatively low power factor supplied by the railway load.

Substations. Step-down transformers are located in the substations, transforming to 11,000 volts for the overhead line construction. One-to-one-ratio transformers, shown in Fig. 15, are

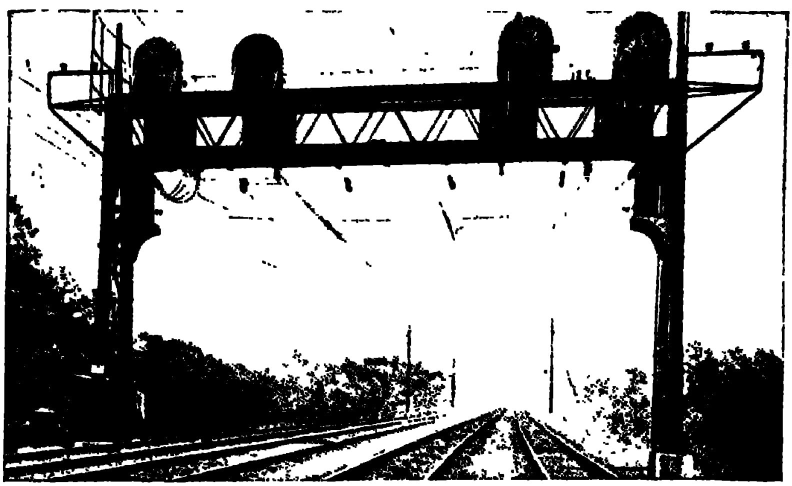


Fig. 15. Typical Anchor and Signal Bridge Located at End of Curve, Philadelphia-Paoli Electrification. Note Track Booster Transformers Mounted at Both Sides
Courtesy of "Electric Railway Journal"

installed at intervals of about 1 mile along the route to obviate the possibility of interference with telephone and telegraph lines, these units being similar in construction to those used by the Norfolk and Western Railway.

Motor Cars. Standard steam-railway coaches, which were originally built with a view to the installation of electrical equipment, are used on the Paoli division. All the cars are motor cars, each being equipped with two 225-hp. single-phase commutator motors, both mounted on the same truck. One of these motors is shown in Fig. 16. All the main portions of the electrical apparatus are mounted on the same end of the car with the motors in

order to secure approximately 60 per cent of the total car weight on the driving axles. The equipment includes, besides the motor, an 11,000-volt pantograph trolley, an oil circuit-breaker, a main transformer, an automatic control equipment with two master controllers, a small motor-generator set for supplying control current, and accessories. One of the novel features of this equipment is the electric air-brake apparatus. With this type of brake the valves on the individual cars are operated by electromagnets instead of by the train piping, which ensures a more rapid braking effect. The motors are geared to the axles through a flexible spring gear, which is designed to soften the vibrations due to the single-phase torque.

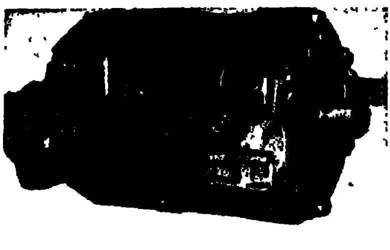


Fig. 16. 225-H P. Single-Phase, Air-Blast Cooled, Double-Feed Motor
Courtesy of Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pennsylvania

Catenary Construction. The overhead construction, Fig. 17, consists of one B.& S. gage copper wire, called the auxiliary messenger, supported from a ½-inch seven-strand steel cable, which is in turn suspended from cross-messengers located at intervals of approximately 300 feet. Below the auxiliary messenger is a No. 000 grooved "phono-electric" wire, from which the pantograph trolley takes the current. This contact wire is clipped to the auxiliary messenger at points midway between the main hangers. The signal bridges, Fig. 15, which are located at distances approximately 1 mile apart, are also utilized in place of a cross-catenary to support the trolley wires.

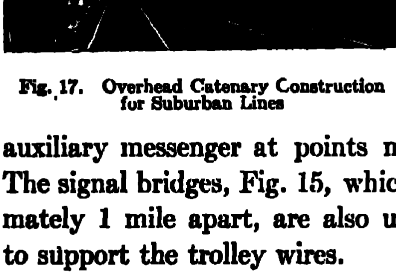


Fig. 17. Overhead Catenary Construction for Suburban Lines

NEW YORK, NEW HAVEN AND HARTFORD RAILROAD

(11000 Volts Single Phase)

General Data. The New York, New Haven and Hartford Railroad enters the Grand Central terminal, which it uses jointly

with the New York Central Railroad. In order to comply with the state legislation requiring electrification, both these roads were forced to withdraw steam engines from the terminal. Operation was started by the New Haven Railroad in 1907, running from Forty-Second Street to Stamford, Connecticut. The system used is 11,000 volts, single phase, 25 cycles, with overhead catenary construction. From Woodlawn to the Grand Central terminal the New Haven Railroad operates over the 600-volt d.c. lines of the New York Central system, so that locomotives and car equipments must be capable of running on either direct current or alternating current, single phase. The New Haven electrification was later extended to New Haven, Connecticut, and most of the

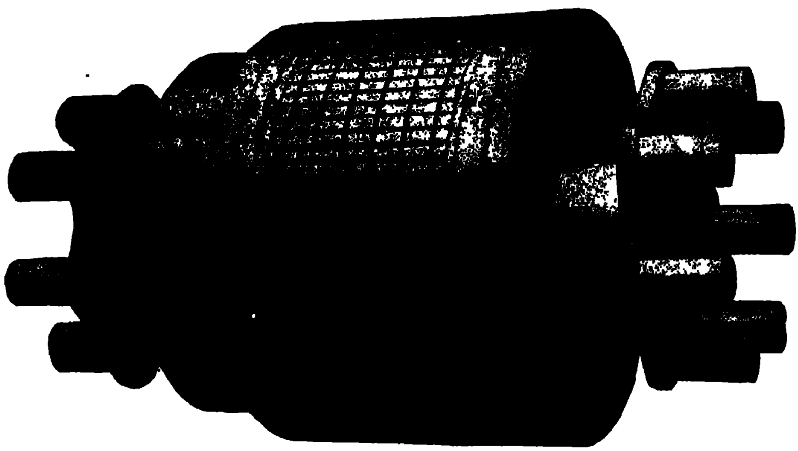


Fig. 18. View of Hollow Armature Shaft and Pin Plate

trains between New York and New Haven are now electrically propelled.

Locomotives. The initial equipment of the New Haven Railroad consisted of forty-one 110-ton electric locomotives, each equipped with four gearless motors connected to the driving wheels by means of pins carried on each end of the armature, Fig. 18. The use of the single-phase a.c. motor on electric railways is discussed in "Electric Railways," Part I. The electrical connections are similar to those employed in the d.c. series motor, but instead of using resistance to limit the current flow, the impressed voltage is reduced by means of taps on the auto-transformer carried by the locomotive. The field frame of the

motor is spring supported from a frame which rests on journal boxes. The armature shaft is a hollow quill which surrounds the axle without coming into contact with it. On this quill are the motor bearings, which preserve correct relation between armature and field. On each end of this quill is a plate, Fig. 18, from which project seven round pins which fit very loosely into corresponding sockets on the inside of each wheel hub, Fig. 19. Between the pins and the sides of the sockets are eccentric coiled springs, which give a flexible bearing.

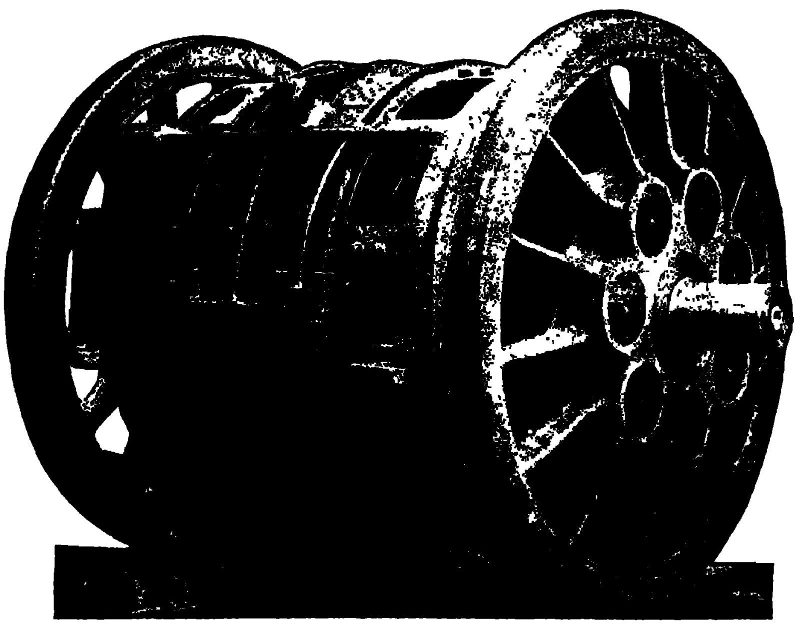


Fig. 19. Motor Mounted on Axle

Freight Locomotives. For freight service the New Haven Railroad purchased thirty-four 120-ton locomotives in 1911. These locomotives were equipped with twin motors, shown by the dotted lines in Fig. 20, on each of the four driving axles, and also employed quill drive in order to obtain flexibility. In 1912 fifteen switching locomotives, Fig. 21, were installed, each weighing 80 tons. Four geared motors are used, each mounted directly above the driving axle and connected through a quill and gears. Table IV gives the principal data on these locomotives, while the trend of design is indicated by the proposed 180-ton locomotive

shown in Fig. 20. In Fig. 22 is illustrated a standard switching locomotive.

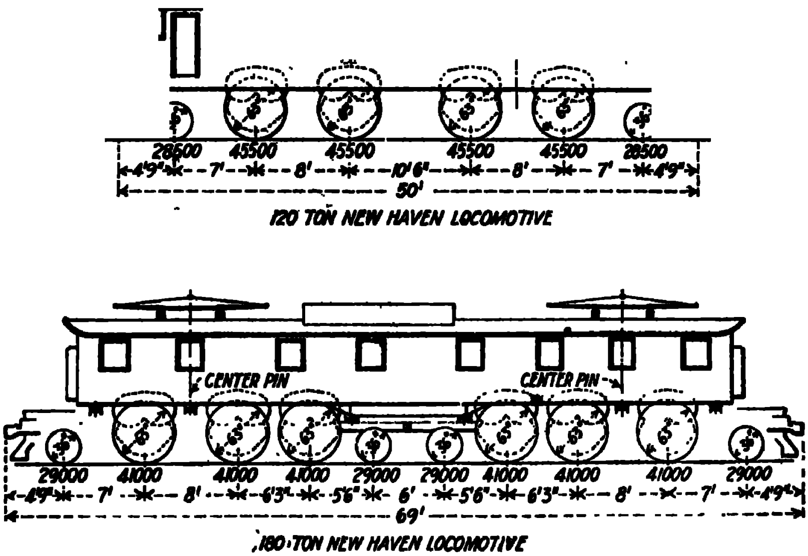


Fig. 20. Elevations of 120-Ton and 180-Ton Locomotives of the New York, New Haven and Hartford Railroad

Fig. 21. Switching Locomotive and Train
Courtesy of Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pennsylvania

Passenger Locomotives. The most recent type of single-phase locomotive was built for passenger service, Fig. 23, and has six driving axles, each of which carries a twin motor with quill drive. Table IV also gives the principal data on this locomotive.

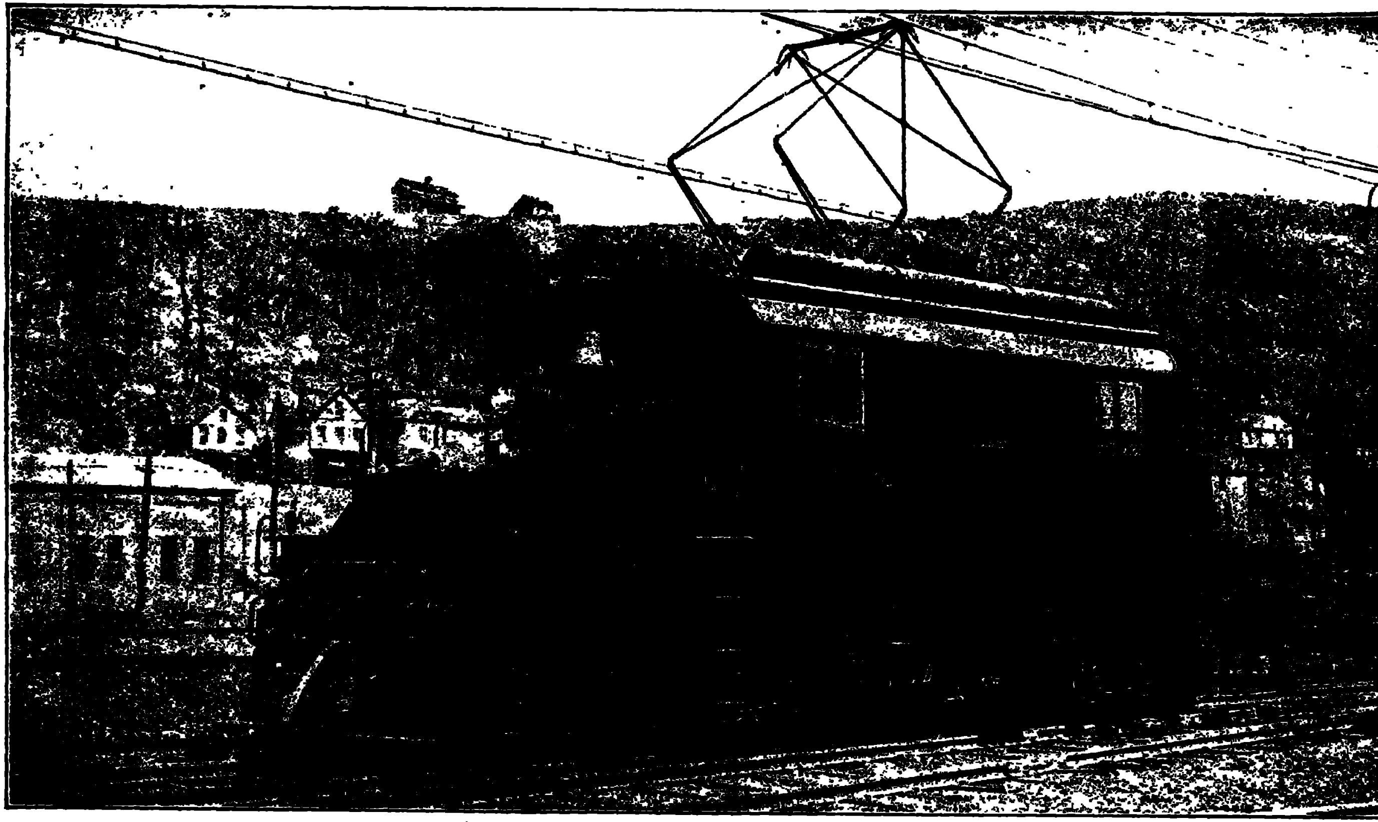


Fig. 22. Standard Electric Switching Locomotive Used on New York, New Haven and Hartford Railroad

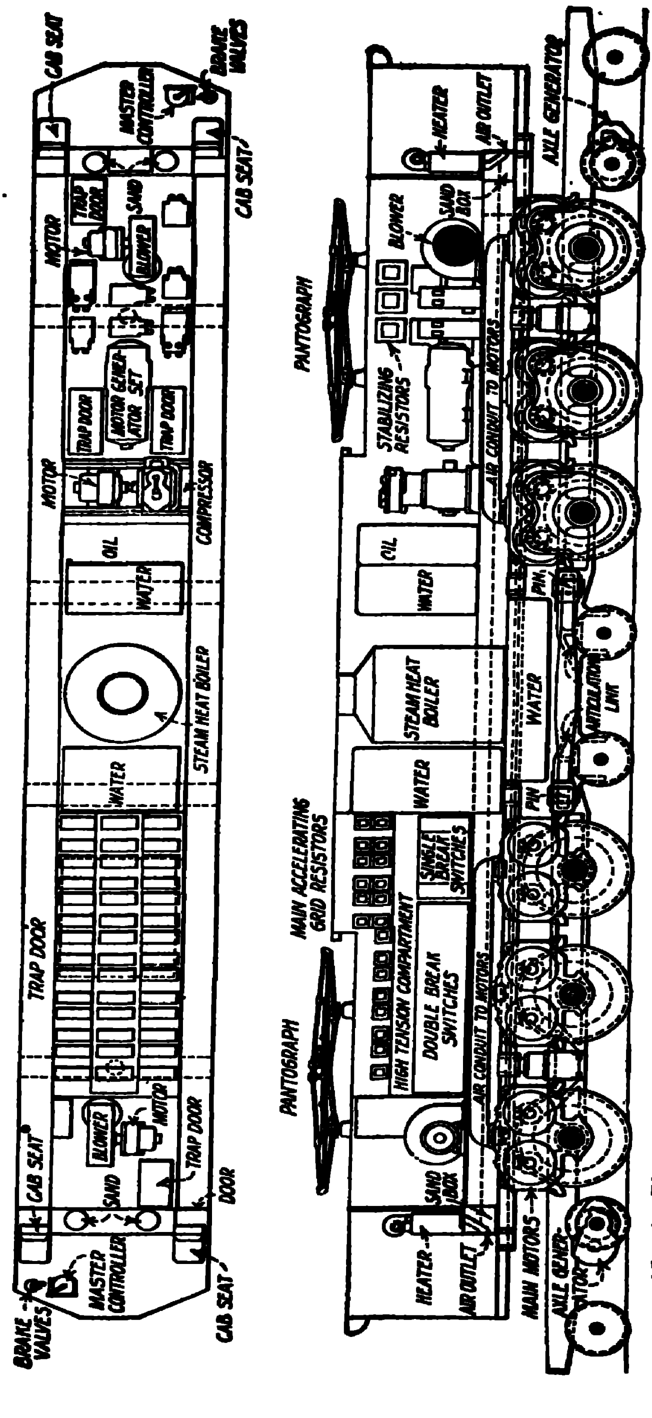


Fig. 23. Elevation and Plan Showing Arrangement of Equipment on Quill-Drive Locomotive of Chicago, Milwaukee and St. Paul Railway

Power Station. A steam power plant, having a capacity of 35,000 kilowatts in eight single-phase steam-turbine-driven units, was built at Coscob, near Stamford, Connecticut, and supplies current at 22,000 volts to the overhead construction. Additional power is also purchased from a New York City plant and fed to the system near New York City. There are no substations in the ordinary meaning of the term, but autotransformers are installed at distances ranging from 3 to 10 miles apart, by means of which the 22,000-volt current is stepped down to 11,000 volts for the locomotives. These autotransformer stations, Fig. 24, also

Fig. 24. Typical Line Auto-Transformer Installation on New York, New Haven and Hartford Railway Electrification

serve to reduce disturbances due to inductive interference with neighboring communication lines. About twenty of these stations are used.

Overhead Line Construction. The overhead construction on this system is of the catenary type, supported on structural-steel bridges located at a distance of 300 feet apart. A large part of the overhead construction is of the double-catenary type, having a supplementary contact wire of special wearing qualities.

CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY

(3000 Volts Direct Current)

General Data. By far the most extensive main-line electrification in the world was installed by the Chicago, Milwaukee and

St. Paul Railway in 1915 and 1916 between Harlowton, Montana, and Avery, Idaho, a distance of 440 miles across the three

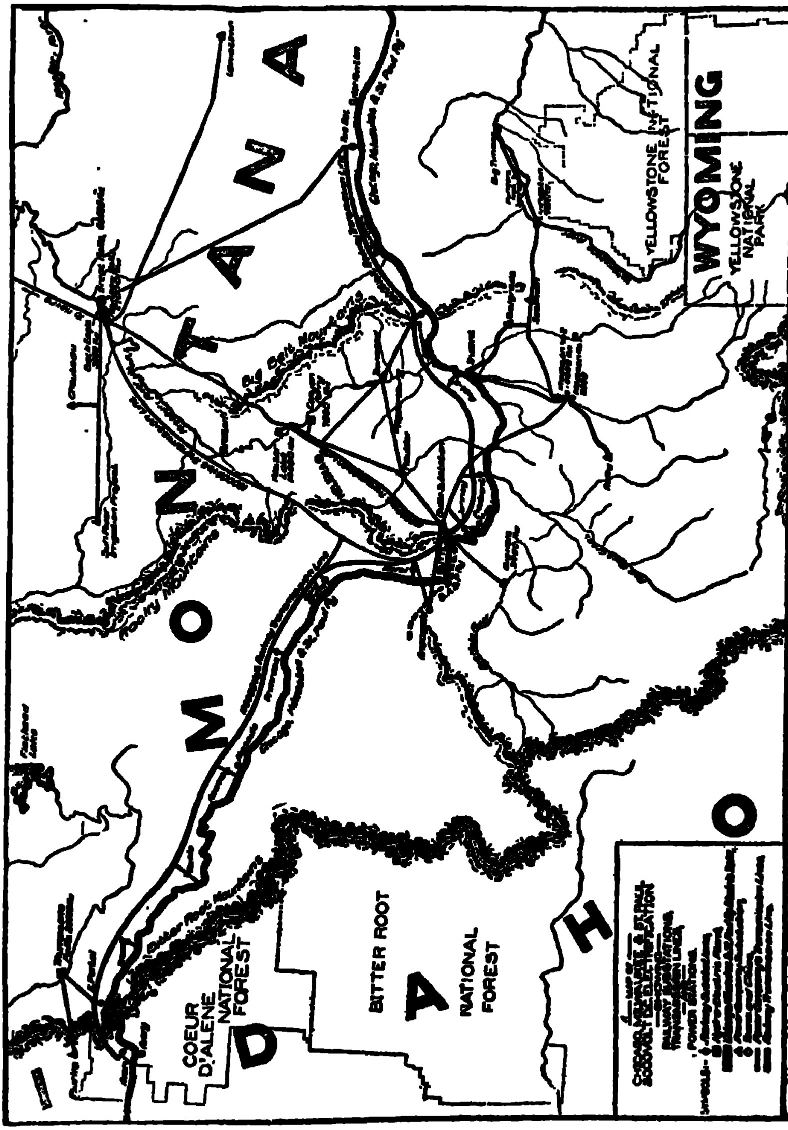


Fig. 25. Map of Mountain District, Chicago, Milwaukee and St. Paul Railway
Courtesy of General Electric Company, Schenectady, New York

main ranges of the Rocky Mountains, the route being shown in Fig. 25. Practically the entire line is single track, with the exception of yards and sidings. The system used is 3000 volts, direct

current, on the trolley with supplementary feeders, positive and negative.

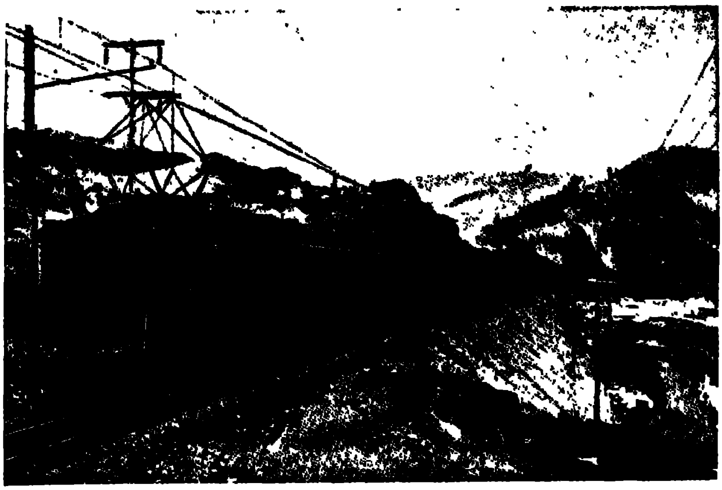


Fig. 26. Train of Eighty-Two Freight Cars in Silver Bow Canyon
Courtesy of General Electric Company, Schenectady, New York

Locomotives. The main-line electric locomotives, Fig. 26, are constructed in two units permanently coupled together, the halves being duplicates and each capable of independent operation. There are thirty freight locomotives, weighing 282 tons each, and twelve passenger units, which are similar in construction, with

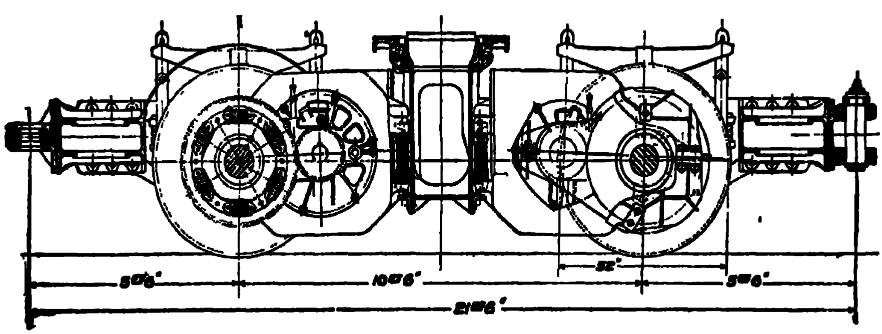


Fig. 27. Details of Main Locomotive Truck, Showing Spring Gear and Spring Nose Suspension
Courtesy of General Electric Company, Schenectady, New York

the exception of a change in gear ratio between the motors and the driving axles and the addition of oil-fired steam boilers for

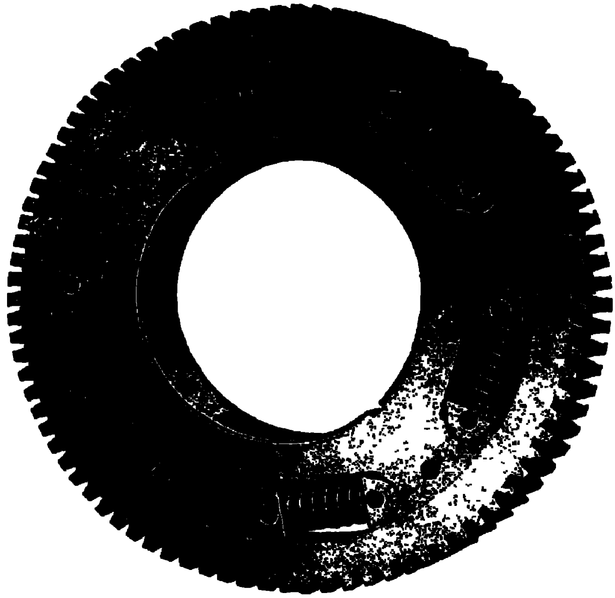


Fig. 28. Spring Gear
Courtesy of General Electric Company, Schenectady, New York

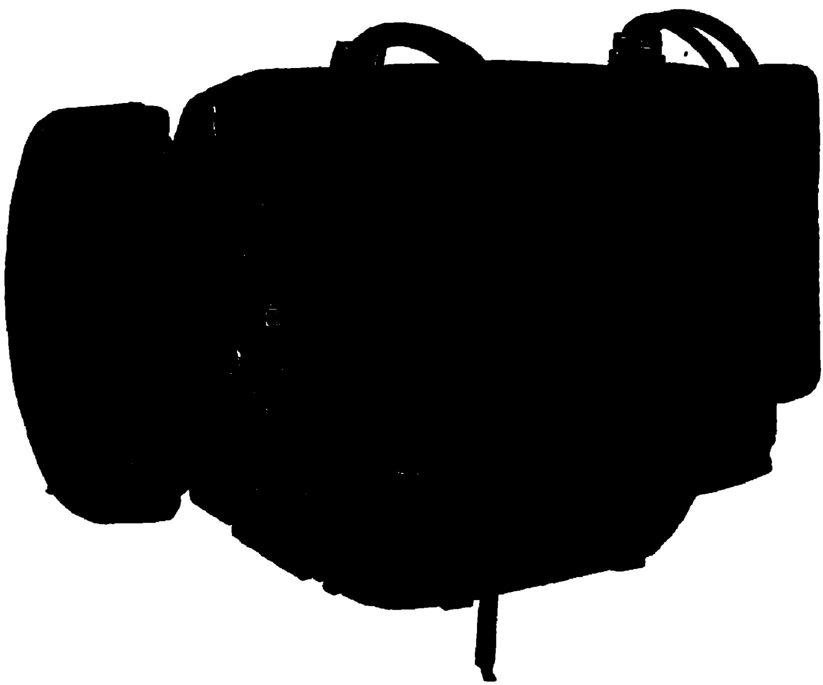


Fig. 29. 1500- to 3000-Volt Motor
Courtesy of General Electric Company, Schenectady, New York

heating the passenger coaches. This additional equipment brings the weight of the passenger units up to 300 tons.

Motors. Each locomotive is equipped with eight 430-hp. commutating-pole railway motors, driving through twin gears from pinions on either end of the motor. The details of the construction are shown in Fig. 27. The locomotive has eight driving axles, and for guiding purposes a bogie truck is used at one end of each half-unit. A flexible connection is obtained

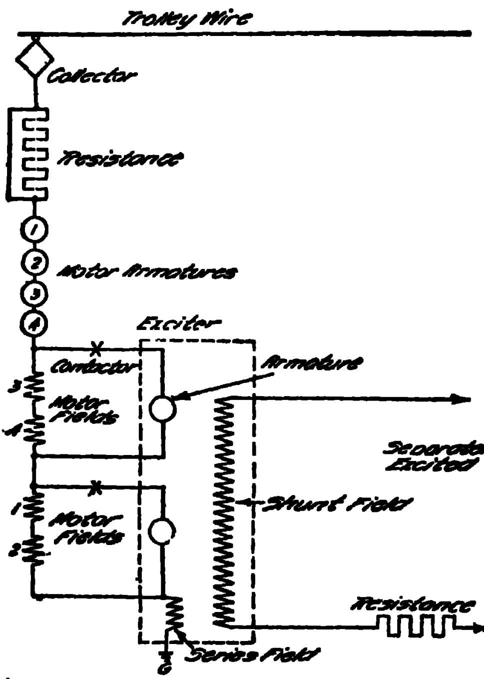


Fig. 30. Simplified Connections for Regenerative Electric Braking, Showing Four Traction Motors and Exciter

between the motor and the driving axle by a spring gear, Fig. 28, and also by the use of a spring-nose suspension, both of which features tend to minimize the effect of shocks and also to reduce the wear on the gears and pinions. The motors, Fig. 29, are similar in construction to the street-railway motor, having longitudinal ducts through the armature core, through which ventilating air is forced from a blower in the cab.

Regenerative Braking. A novel feature of these locomotives is the ability to regenerate on the down grades, holding back the

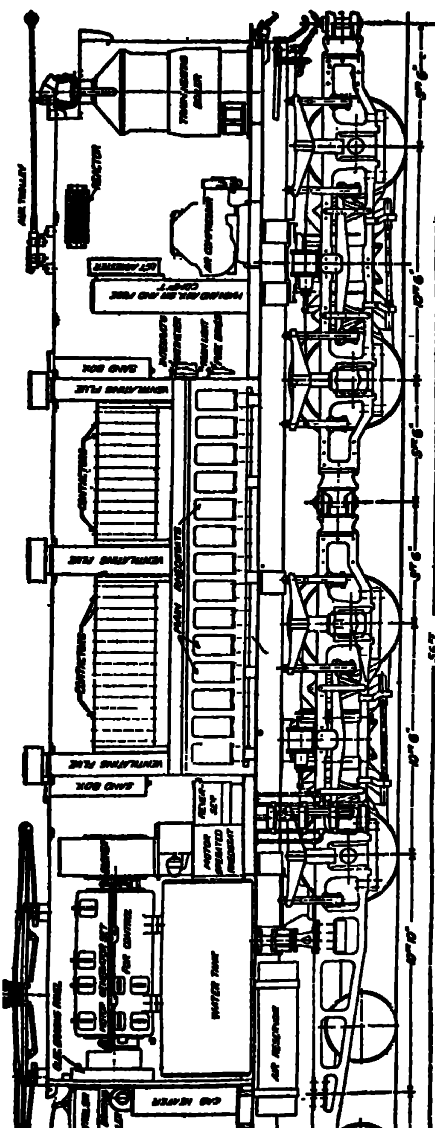


Fig. 31. Elevation of Half Locomotive Unit, Showing Arrangement of Apparatus
Courtesy of General Electric Company, Schenectady, New York

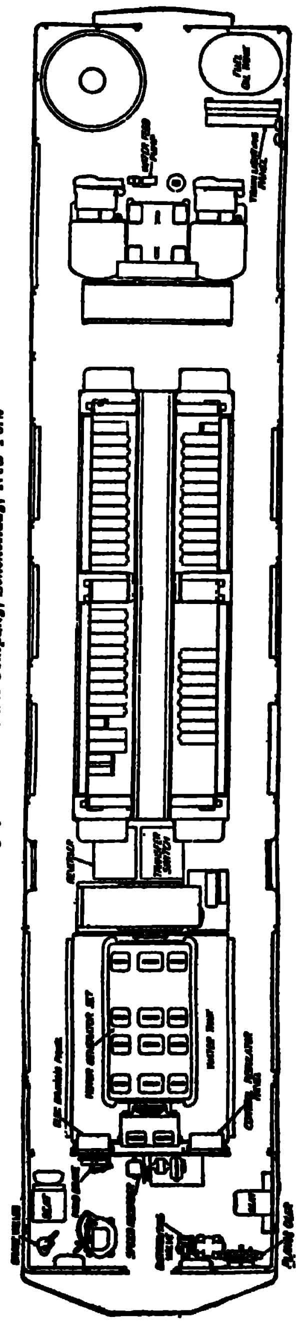


Fig. 32. Plan of Half Locomotive Unit, Showing Arrangement of Apparatus
Courtesy of General Electric Company, Schenectady, New York

train without the use of air brakes. This is accomplished by changing the connections of the motors so that the energy of the descending train due to gravity is utilized to generate electricity and send it back through the trolley wire to the substation. Two objects are thus accomplished: first, the train is restricted to a safe speed down the hill; and second, electric power is returned for use by other trains. The principal connections for regenerative braking are shown in Fig. 30.

Speed. The freight locomotives are capable of handling the rated load of 1250 tons each up the maximum 2 per cent grade at

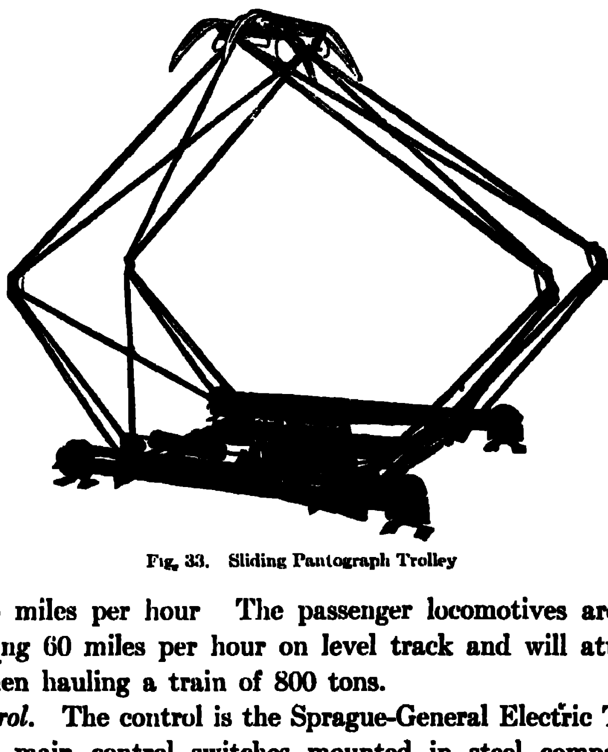


Fig. 33. Sliding Pantograph Trolley

about 15 miles per hour The passenger locomotives are geared for running 60 miles per hour on level track and will attain this speed when hauling a train of 800 tons.

Control. The control is the Sprague-General Electric Type M, with the main control switches mounted in steel compartments inside the locomotive cab. As these switches carry the main 3000-volt current, they are located so as to make accidental contact by operators impossible.

Motor-Generator Set. In each half of the locomotive a motor-generator set is installed, which furnishes low-voltage current for the control circuits, headlights, cab lighting, and, on the passenger

locomotives, for charging storage batteries on the coaches. A blower for ventilating the traction motors is also direct connected to one end of this set. The general arrangement of the apparatus on one of these half-units is shown in Figs. 31 and 32.

Pantograph Collector. Current is taken from the overhead trolley by means of sliding pantograph collectors, one of which is mounted on each half of the locomotive. These collectors, Fig. 33, are of the double-pan type, operating through a range of from 17 to 25 feet above the rail. The contact elements are

Fig. 34. Chicago, Milwaukee and St. Paul Railway Electric Locomotive
Courtesy of General Electric Company, Schenectady, New York

somewhat novel, being of the same metal as the trolley wire, so that the current passes from copper to copper.

Use of Compressed Air. The air-brake equipment is practically the same as that used on steam locomotives, except that motor-driven air compressors are used to furnish the compressed air. Compressed air is also used for operating whistles, bell ringers, sanders, flange oilers, pantograph trolleys, and part of the control equipment.

Switching Locomotives. Two switching locomotives, Fig. 34, are also used on this electrification, weighing 70 tons each, and

with all the weight on the driving axles. These units are of the swivel-truck type, equipped with four geared motors designed for

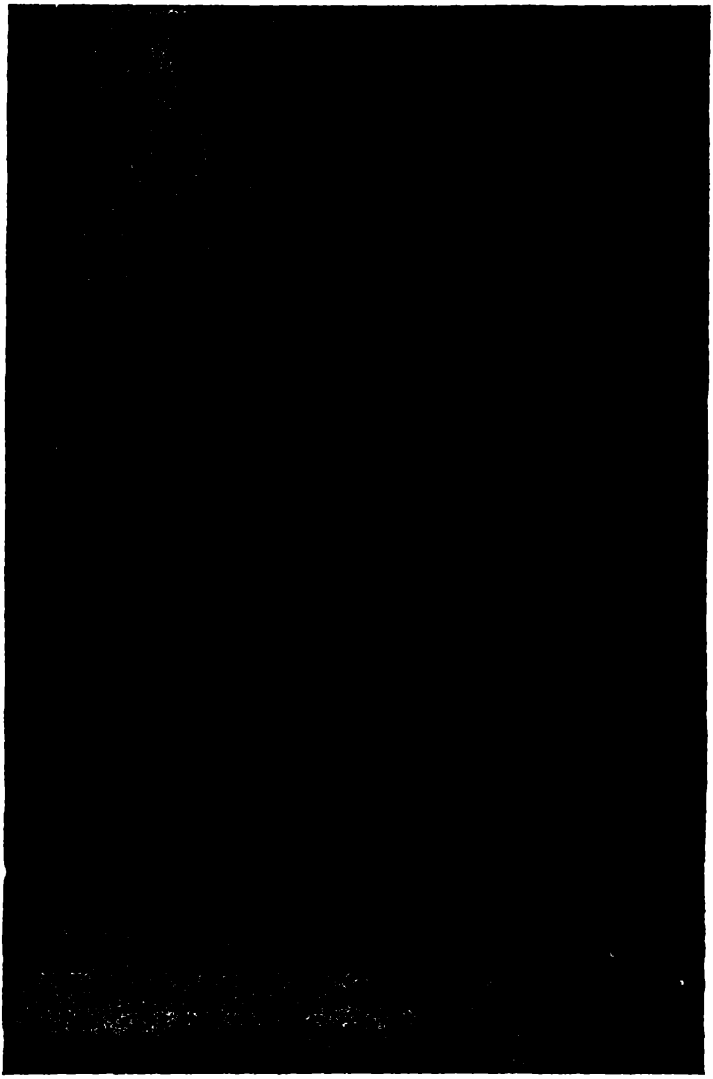


Fig. 35. Switchboard in Piedmont Station
Courtesy of General Electric Company, Schenectady, New York

1500-volt operation with an insulation of 3000 volts to allow for operating two in series in the same manner as the main-line locomotives.

Substations. Electric power generated in hydroelectric stations is purchased from the Montana Power Company at several points along the line and transmitted along the road over a 100,000-volt, three-phase, 60-cycle transmission line carried on wooden poles. There are fourteen substations, each equipped with synchronous motor-generator sets of the three-unit type supplying 3000 volts from two d.c. generators connected in series.

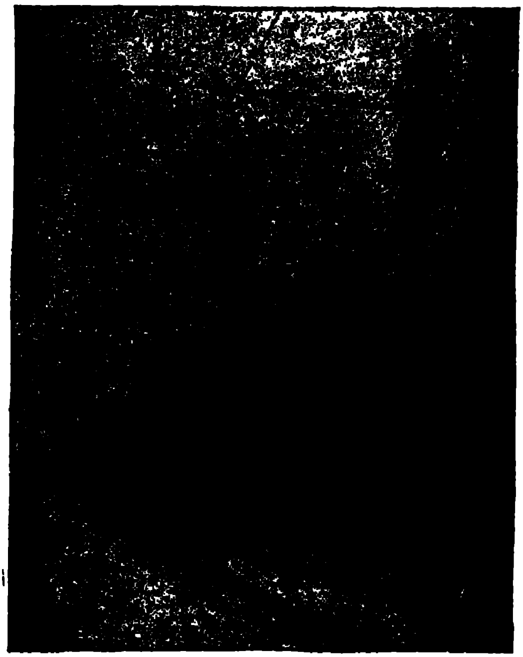


Fig. 36. Overhead Construction on Tangent Track
Courtesy of General Electric Company, Schenectady, New York

One of the substation switchboards is shown in Fig. 35. The principal connections between the power lines are shown in Fig. 25.

Regenerative Braking. In connection with the regenerative braking feature on this system the motor-generator sets in these substations are so constructed that the d.c. units will function as motors when supplied with power and operate the synchronous motor as a generator, sending three-phase current at 2300 volts to the step-up transformers and thence back over the three-phase transmission line. This method of operation takes place when there are no other locomotives near the section fed by the sub-

station to use the 3000-volt current direct. It frequently happens, however, that a train going down one side of the mountain pumps back current to another train coming up the other side, so that very little power is taken from the substation.

Overhead Line Construction. The 3000-volt direct current supply is fed to the locomotives through a so-called twin-catenary trolley, supported from wooden poles by means of bracket construction on single-track sections, Fig. 36, and span wires on double track and in switching yards. The trolley wires are of No. 0000 copper, suspended side by side from the same steel messenger wire by independent loop hangers, alternately connected to each wire. Currents as high as 2000 amperes can be collected by a single locomotive without perceptible sparking at the contact, both in high-speed passenger service and with heavy freight trains. Where two locomotives are used for a single train, this corresponds to 12,000 kilowatts, which is beyond the requirements of any train-haulage problem to be considered.

NORFOLK AND WESTERN RAILWAY

(11000 Volts Alternating Current)

General Data. The electric zone of the Norfolk and Western Railway, extending from Bluefield to Vivian, West Virginia, represents one of the heaviest electrifications now in operation.

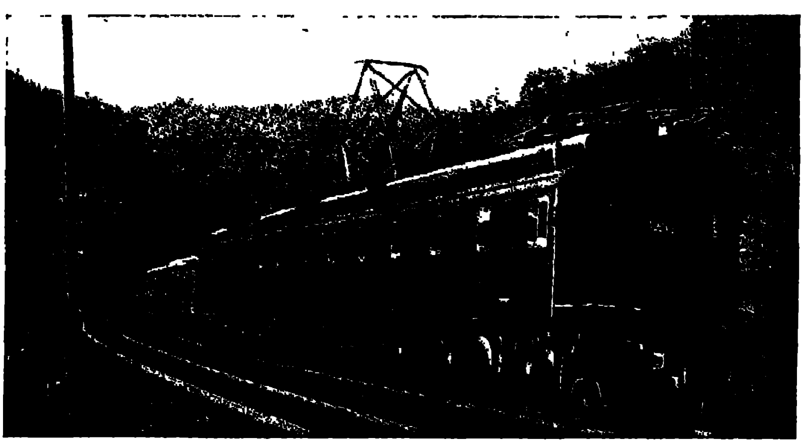


Fig. 37. Electric Locomotive, Comprising Two Units or Halves, Hauling Heavy Coal Train on Eckhorn Grade, Norfolk and Western Railway
Courtesy of "Railway Review"

The road is double tracked on both sides of the Elkhorn tunnel at the summit of the mountain range, but only a single track is laid through the tunnel. This road is a coal-hauling line, and the traffic is very heavy. Trains of 3250 tons are hauled up the maximum grade, using two locomotives, one acting as a pusher on the 2 per cent grade. The system used is 11,000 volts, single phase, 25 cycles, which is transformed to three phase for use with the locomotive motors.

Locomotives. The electric locomotives, Figs. 37 and 38, are of the two-unit type, permanently coupled together and having a total weight of 270 tons. Two hundred and twenty tons of this weight is on the driving axles, and the remainder is on the guiding trucks. Each unit has two main trucks, equipped with two driving axles included in a rigid wheel base with a radial two-wheel guiding truck.

Motors. Mounted on each of the main trucks are two three-phase induction motors with wound secondaries for two-speed operation. These two motors mesh into a single gear carried on a jack shaft, from which power is transmitted to the two driving axles by means of side rods. The operating speed with all motors connected in parallel is 14 miles per hour with the slow-speed motor combination and 28

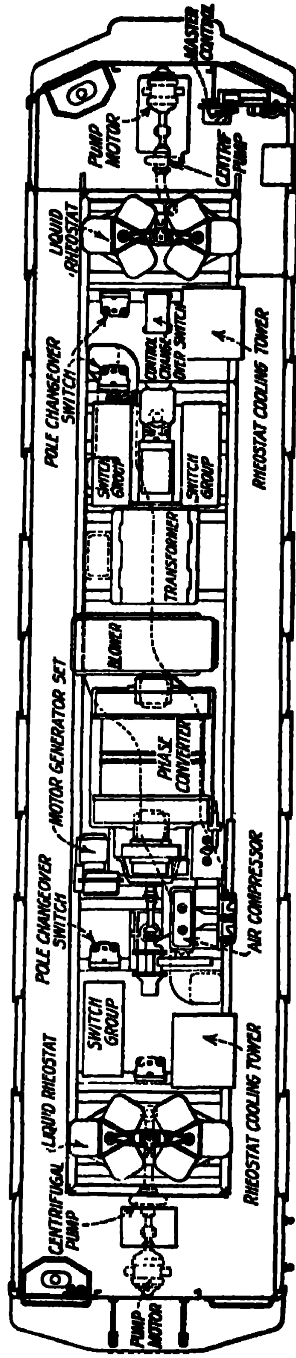


Fig. 38. Plan with Arrangement Shown Diagrammatically, Electric Locomotive of Norfolk and Western Railway
Courtesy of "Railway Review"

miles per hour with the rearrangement of the number of poles on the motor.

Single-phase current is taken into the motor through a pantograph and delivered to step-down transformers and passes at the low pressure to a phase converter, which operates continuously when the locomotive is in service. This machine converts the single-phase current into three-phase current by means of a two-phase to three-phase connection. Attached to the extended shaft of this converter is a blower for cooling the motors, transformers, and other parts and also a compressor, which is operated by means of

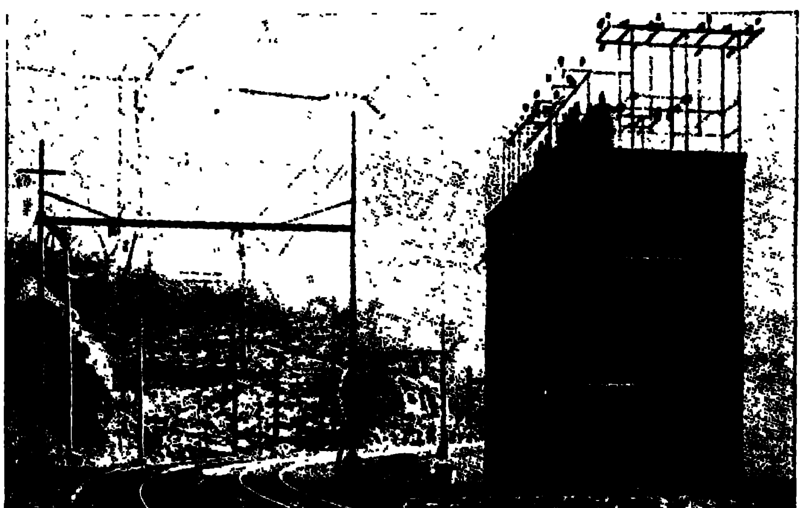


Fig. 30. Exterior of Maybury Substation, Norfolk and Western Railway, Showing Typical Design
Courtesy of "Railway Review"

a clutch actuated by the air pressure. The speed of the locomotive is regulated by inserting resistance in the secondaries of the induction motors by means of liquid rheostats, one being supplied for each motor. The resistance of these rheostats is gradually cut out as the locomotive speeds up, and when the operating speed is reached, the rheostat tanks are short-circuited.

Regenerative Braking. These locomotives, being of the induction-motor type, will regenerate automatically on down grade when the speed of the train rises slightly above the synchronous speed of the motors. Regenerative braking, however, is limited to this

particular speed in these units, either 14 miles per hour with the eight-pole arrangement, or 28 miles per hour with the four-pole arrangement.

Substations. There are five substations, similar to that illustrated in Fig. 39, spaced approximately 6 miles apart, in which single-phase current is received at 44,000 volts and stepped down to 11,000 volts for the trolley feeders. Since these stations contain no rotating apparatus, they can be operated without attendance other than occasional inspection.

Power Station. Power is derived from a steam power station, Fig. 40, located at Bluestone, which is about 11 miles from Bluefield.

Fig. 40 Turbine Room of Power Station, Norfolk and Western Railway, Showing Main Generating Unit; Operating Gallery on Level with Crane Track; Low-Tension Switching Room on Main Floor Level
Courtesy of "Railway Review"

field. This location was selected on account of the facilities for obtaining water for boiler feed and for condensing purposes. The electric generating equipment consists of three 10,000-kilowatt horizontal units, operating at 11,000 volts and feeding the several substations through step-up transformers at 44,000-volt transmission. An interesting feature of this station is the provision for absorbing regenerated power when a train is sending current back to the station during regeneration. For this purpose water rheostats are provided, which are automatically connected across the generator bus when the regenerated power reaches a

certain value. This arrangement protects the generators from operating as motors and causing injury to the steam turbines.

Overhead Construction. The catenary system, Fig. 41, consists of a No. 000 grooved contact wire, supported at a uniform height of 24 feet above the top of the rails. The messenger is a ½-inch galvanized-steel stranded cable, supported from steel supporting structures located 300 feet apart. Just above the No. 000 grooved contact wire is a No. 0 auxiliary steel messenger wire, from which the contact wire is supported by clips spaced about 15 feet apart, but so located that they are equally distant from the main hangers.

Telephone and Telegraph Interference. In order to protect neighboring communication circuits from the effects of single-

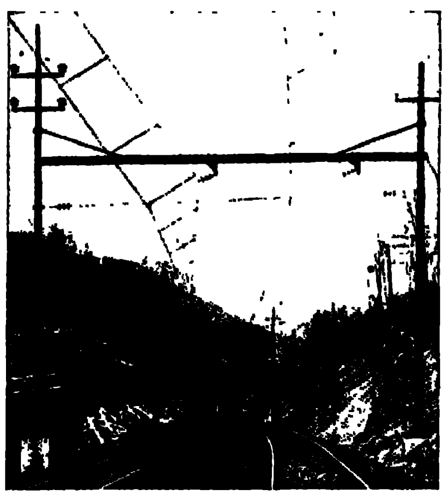


Fig. 41. Typical Tubular Steel Pole Structure for Main Line, Norfolk and Western Railway Electrification
Courtesy of "Railway Review"

phase interference, transformers having a ratio of 1 to 1 are installed at points approximately 1 mile apart over the entire line. The primary of these transformers is connected into the trolley circuit, and the secondary to the rail circuit, thus preventing ground current from leaving the running rails. This method of protection seems to be quite effective, and little trouble is experienced with single-phase interference.

BUTTE, ANACONDA AND PACIFIC RAILWAY

(2400 Volts Direct Current)

General Data. The Butte, Anaconda and Pacific Railway is an ore-hauling road operating between Butte and Anaconda, Montana, a distance of about 30 miles. Several passenger trains, similar to the one shown in Fig. 42, are run daily between the two cities; and ore trains, Fig. 43, weighing as much as 5000 tons, are hauled from the mines at Butte to the smelters at Anaconda. The annual haulage of ore reaches several million tons.

Fig. 42. 80-Ton, 2400-Volt Locom[illegible] on Butte, Anaconda and Pacific Railway
Courtesy of General Electr[illegible]mpany, Schenectady, New York

Electric locomotives were first put in service in 1913 and all steam engines were replaced in November of that year. The prime reason for electrification was economy; operating results show a saving equal to more than 20 per cent on the investment required.

Electric Locomotives. The initial equipment included fifteen freight and two passenger locomotives weighing 80 tons each and differing only in the gear ratio of the motors. Additional locomotives have since been purchased, making a total of twenty-eight units now in service. These locomotives are of the articulated

Fig. 43. Electric Trains at Entrance to Silver Bow Canyon on Chicago, Milwaukee and St. Paul, and Butte, Anaconda and Pacific Railways, Operating at 3000 and 2400 Volts, Direct Current

Courtesy of General Electric Company, Schenectady, New York

double-truck type with all the weight on the drivers, the weight being carried on semielliptic springs suitably equalized.

Arrangement of Apparatus. In each end of the cab is an engineer's compartment containing control apparatus. The cab is of the box type, extends the entire length of the locomotive, and is provided with both end and side doors.

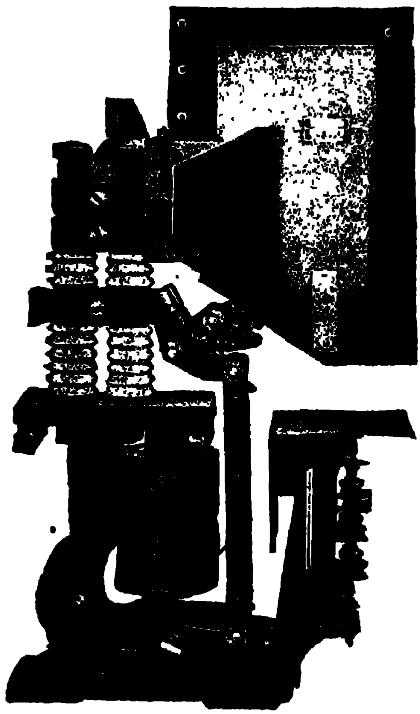


Fig. 44. 2400-Volt General Electric Contactor

The central channels forming a part of the underframe are enclosed and are utilized as distributing air ducts for the forced ventilation of the motors. The air is conducted through the center pins, which are hollow, into the truck transoms and thence to the motors. The engineer's compartment at each end of the cab contains the operator's seat, controller, air-brake valves, bell and whistle ropes, ammeter, air gages, sanders, and other control apparatus within immediate reach of the engineer.

The contactors, Fig. 44, reverser, and rheostats, which are located in the central portion of the cab, are mounted in two

banks running lengthwise of the compartment and are conveniently arranged for cleaning, inspection, and repair. All apparatus and circuits carrying 2400 volts are thoroughly protected from accidental contact.

Motors. The motors are of the GE-229-A commutating-pole type, wound for 1200 and insulated for 2400 volts. The method of ventilation is similar to that of the ventilated motor previously described, but the air is circulated by a blower mounted on the end of the dynamotor shaft. The motors have a pinion on each end which meshes in a spring gear, Figs. 28 and 45, on each side of the axle.

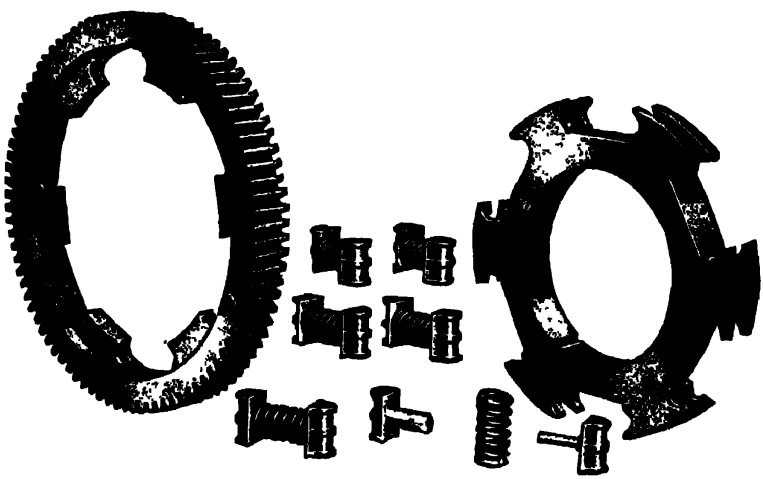


Fig. 45 Spring Gear Disassembled
Courtesy of General Electric Company, Schenectady, New York

Control. The control is the Sprague-General Electric Type M, multiple unit, operating the four motors in series and in series-parallel. Two 1200-volt motors are permanently connected in series. The controller provides ten steps in series and nine in series-parallel. The transition between series and series-parallel is effected without opening the motor circuit, and there is no appreciable reduction in tractive effort during the change. The transfer of circuits at this point is made by a special change-over switch, which is operated electropneumatically.

Pantograph. Current is collected by overhead roller pantographs, Fig. 46, pneumatically operated and controlled from either engineer's compartment by an air valve.

Dynamotor. For operating the control equipment and the air compressor and for lighting the locomotive and cars 600-volt cur-

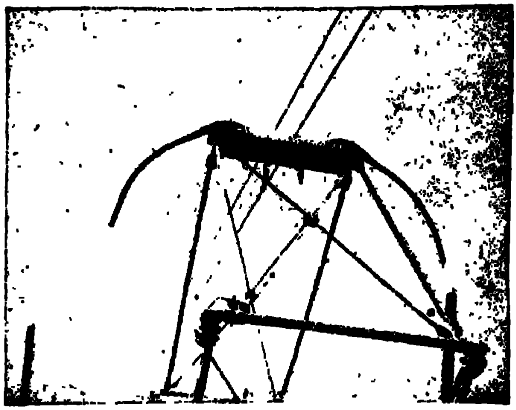


Fig. 46. Pantograph in Operation on Single Trolley Wire
Courtesy of General Electric Company, Schenectady, New York

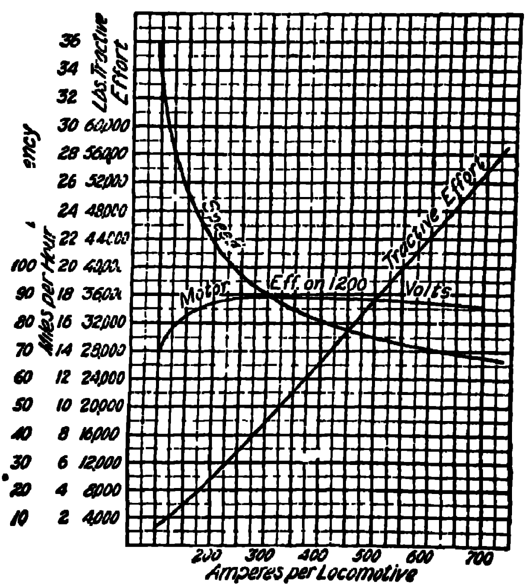


Fig. 47. Characteristic Curves for Freight Locomotive
Courtesy of General Electric Company, Schenectady, New York

rent is supplied from the 2400-volt to 600-volt dynamotor installed on each locomotive. The machine is similar in construction to the 1200-volt to 600-volt dynamotor, having two distinct sets of arma-

ture coils wound on the same core and brought out to a commutator at each end. One of these windings is designed for 1800 volts and the other for 600 volts, the two commutators being connected in series across the 2400-volt circuit. The load current is taken from the 600-volt commutator. Characteristic curves for this type of freight locomotive are shown in Fig. 47.

Electric Hot-Air System. All the passenger and baggage cars now used between Butte and Anaconda are heated as well as lighted by electricity. Each car is heated from a single heating unit installed underneath the car floor and supplied from a 2400-volt bus connected directly to the 2400-volt bus on the locomotive. This unit has a maximum capacity of 25 kilowatts and is used to heat the air, which is distributed to different parts of the car by means of a small motor-driven blower.

Substations. Power is purchased from the Montana Power Company, and seven three-unit motor-generator sets of 1000 kilowatts capacity each are installed in two substations owned by the power company. Three-phase 60-cycle power is received at 100,000 volts, stepped down to 2300 volts, and transformed to 2400 volts, direct current.

Overhead Construction. The overhead line is an eleven-point catenary supporting a No. 0000 trolley wire by means of loop hangers, which allow a vertical motion of the contact wire without lifting the messenger. The line is designed for the use of roller pantograph collectors such as shown in Fig. 46.

Other Important Electrifications. The foregoing descriptions will serve to bring out the main features of both a.c. and d.c. electrification. There are, however, several other important steam railway electrifications which are worthy of mention, concerning which the principal features are outlined in Tables I and IV. It will be of interest to the student to make a comparison of the various data in these tables.

Dictionary of Electrical Terms

A.C.: Abbreviation for alternating current.

abscissa: A distance measured horizontally to the right and left of a vertical line.

absolute units: A unit of measurement which has been determined from certain physical properties and upon which all other units are based.

accumulator: A storage battery.

acid proof paint: A paint made especially to resist the action of acid.

admittance: A unit used in alternating current circuits, which is the opposite to impedance, measured in ohms.

aerial: Wires supported above ground and used for receiving or sending electrical waves.

advance wire: An alloy of copper and nickel used for electric heating units.

air blast transformer: A transformer cooled by forcing a circulation of air around its windings.

air gap: Air space between magnetic poles. Space between stationary and rotating parts of an electric motor and generator.

algebraic: Taking into account the sign used in algebra.

alive: Carrying a voltage or current.

alkaline battery: A storage battery using an alkali instead of acid for electrolyte Edison Cells.

all-day-efficiency: The total output divided by the total input of energy for the entire day.

alloy: A metal composed of two or more different metals.

alphaduct: A flexible non-metal conduit.

alternating current: An electric current that reverses its direction of flow at regular intervals.

alternation: One vibration instead of a cycle. One-half a cycle of alternating current.

alternator: An electric generator producing alternating current.

aluminum: A white metal, light in weight but having a higher electrical resistance than copper.

aluminum cell arrester: A lightning arrester using a series of aluminum plates and an electrolyte which forms a thin insulating film on the plates at normal voltage, but becoming a conductor when a high voltage, like lightning, occurs. As soon as the high voltage is reduced to normal, the insulating film is formed again.

aluminum rectifier: A jar containing aluminum plates and iron or lead plates immersed in a solution of ammonium phosphate and which will allow current to flow, though only in one direction, from the iron or lead plates to the aluminum plate.

amalgam: An alloy of mercury or quicksilver with other metals.

amber: A yellowish resinous substance that can be used to produce static electricity by friction.

American wire gauge: The gauge is used for designating the sizes of solid copper wires used in United States. Formerly called Brown and Sharpe (Best gauge).

ammeter: The practical unit that indicates the rate of flow of electricity through a circuit.

ammeter shunt: A special low resistance conductor connected to the terminals of an ammeter so as to carry nearly all the current, allowing only a very small current to flow through the instrument itself.

ampere: The practical unit that indicates the rate of flow of electricity through a circuit.

ampere-hour: The quantity of electricity delivered by a current of one ampere flowing for one hour. Used in rating storage batteries.

ampere-hour meter: An instrument that registers or records the number of ampere-hours of electrical energy that have passed througn a circuit.

ampere-turn: The amount of magnetism or magnetizing force produced by a current of one ampere

flowing around a coil of one turn. The product of the current flowing through a coil by the number of turns or loops of wire on the coil.

amplifier: A device by which weak currents or sounds acting on another circuit are increased in strength.

anchor: A metal placed in the ground and to which a guy wire from a pole is attached.

angle of dip: The number of degrees that one end of a magnet dips or points downward.

angle of log and lead: The distance expressed n degrees that an alternating current logs or leads the voltage wave. The cosine of this angle is called the power factor.

anion: The ion which moves toward the anode in an electrolytic cell.

anneal: To soften by heating and allowing to cool slowly.

annunciator: An electric signal equipment having a number of push buttons located at different places which are wired to an electromagnet in the annunciator box. Press any push button and it causes a signal to be displayed showing what button was operated.

annunciator wire: A soft copper wire that has two layers of cotton threads wound on it in opposite direction and covered with paraffin wax.

anode: The terminal or electrode through which current flows into the electrolyte.

antenna: Wires arranged to receive or send out electromagnetic (Radio) waves into the air.

anti: A prefix, meaning opposite, against, opposed to, etc., to the word that follows it.

apparent E.M.F.: The apparent voltage as measured by the drop in pressure due to current flowing through the resistance.

apparent efficiency: In alternating current apparatus it is the ratio of net power output to volt-amperes input.

apparent watts: The product of volts times amperes in an alternating current circuit.

arc: The flow of electric current across a gap in a circuit which causes a light or glow.

arc furnace: An electric furnace in which heat is produced by an arc between two electrodes.

arc lamp: A lamp producing light from an arc.

arc lamp carbon: A carbon rod between which the arc is produced in an arc lamp.

arc light generator: A generator producing a constant current for an arc light circuit. Nearly obsolete.

arc welding: Joining two pieces of metal together by use of an electric arc.

argon: An odorless, colorless, inert gas taken from the air. Used in some types of incandescent light bulbs.

armature: The rotating part of a direct current motor or generator. The part of the generator that delivers electrical energy or the part of the motor that receives electrical energy from the circuit. Also a piece of iron or steel joining the poles of an electromagnet

armature air gap: The air space between the stationary and rotating parts of a motor or generator where the magnetic lines of force pass from one to the other.

armature back ampere turns: The magnetic field produced by current flowing in the armature winding that opposes and reduces the number of magnetic lines of force produced by the field magnets of a motor or generator.

armature band: A group of wires wound closely together, or a metal band placed on the coils of the armature to hold them in place.

armature bar: Copper bars used in place of wire winding the armatures of large generators and motors.

armature bore: The space between opposite pole pieces in which the armature revolves.

armature circuit: The path that the current takes in flowing through the windings from one brush to another.

armature coil: The loop or coil of copper wire placed on the armature core and which forms part of the winding.

armature core: The laminated iron part of the armature, formed from thin sheets or disks of steel, and on which the windings are placed.

armature current: The current flowing from the armature of a generator or to the armature of a motor. It does not include the current taken by the shunt field coils.

armature disks: Thin sheets of iron or steel used in building up the armature core.

armature demagnetization: The reduction in the effective magnetic lines of force produced by the armature current.

armature reaction: The effect that the magnetism produced by the current flowing in the armature has on the magnetism (magnetic lines of force) produced by the field coils.

armature resistance: The resistance of the slip rings on commutator and windings of the armature measured between rings or brushes.

armature slot: The groove or slot in the armature core into which the coils or windings are placed.

armature stand: A device for supporting or holding an armature by the shaft when it is being wound or worked on.

armature tester: Any device or instrument used for locating faults or defects in the armature winding.

armature tooth: The metal between the slots in an armature core.

armature varnish: A liquid put on the field and armature windings to improve the insulation of the cotton coverings on the wires.

armature winding: All of the copper wire placed on the armature and through which current flows when the machine is operating.

armored cable: Rubber-covered wires that have been covered with an iron, steel, or other flexible metallic covering. Often called BX.

artificial magnet: A manufactured permanent magnet, as distinguished from natural magnets.

asbestos: A mineral fiber formed from a certain rock. It is a poor conductor of heat and can withstand high temperatures. Used to insulate wires exposed to a high temperature.

astatic system: An arrangement of two parallel magnets with the north end of one pointing the same way as the south end of the other, so that the two together make a very poor compass needle.

astatic galvanometer: A galvanometer in which the moving parts are arranged in an astatic system or manner.

astatic meter: A meter in which the moving part of element is arranged in an astatic system.

asynchronous: Not having the same frequency, not synchronous; not in step or phase.

asynchronous generator: An induction generator.

asynchronous motor: An induction motor. A motor whose speed is not synchronous with the frequency of the supply line.

atmosphere: The air surrounding the earth. A pressure of 1 atmosphere is 14.7 pounds to the square inch.

atmosphere electricity: Static electricity produced in the sky or between clouds.

atom: The smallest particle or unit of matter that can be chemically united.

atomic weight: The weight of one atom of a chemical element as compared to the weight of an atom of hydrogen.

atonic interrupter: A special interrupter that can be adjusted to operate at a large number of different frequencies.

attachment plugs: A plug that is screwed into a lamp socket, connecting the two wires from an electrical appliance to the circuit.

attenuation: The weakening of an alternating current that flows along a line that has resistance and capacity or leakage.

Aurora Borealis: A light or glow sometimes seen in the northern sky on certain nights.

auto call: A device that sounds a certain code of signals in various places; in a building or factory.

auto-transformer: A transformer in which one winding or coil serves both for the primary and the secondary circuit.

automatic: A device that is operated by certain changes or conditions in an electric circuit and which is not controlled by any person.

automatic telephone: A telephone system where the connection from one party to another is made by means of automatic switches, without the aid of an operator

automatic time switch: A switch operated at certain times by means of a clock.

automotive: Self propelled vehicles, such as automobiles, trucks, tractors and motorcyles.

automobile battery: The storage battery u ed in an electric vehicle. The storage battery used for starting and lighting a gasoline automobile.

automobile fuse: A small fuse used to protect the generator and lighting circuits on an automobile

auxiliary: Extra, or something added to the main one

auxiliary bus: A second bus that may have a different voltage from the main bus and to which a few machines are connected

auxiliary circuit: Another circuit besides the main circuit, often a control circuit.

auxiliary switch: A switch operated or controlled by the action of another circuit.

B

b: A symbol used for "susceptance" in an alternating current circuit.

B: A symbol for magnetic flux density.

B.B.: Abbreviation for Best Best iron telephone wire.

B-battery: The radio battery that keeps the plate of an electron tube positive in relation to the filament.

B.S.G.: British Standard Gauge.

B. board: One of the switchboards in a large telephone exchange where one subscriber is connected to another.

B.t.u.: British thermal unit; the heat required to raise the temperture of 1 pound of water 1 degree F.

B.W.G.: Birmingham wire gauge. The same as Stubs' Copper wire gauge.

BX: A term often used for flexible armored cable.

B. & S.: Brown & Sharpe wire gauge which is the same as American wire gauge.

babbitt metal: An alloy of lead, tin, copper, zinc, and antimony used for bearings of electrical machines.

back pitch: The distance between the two sides of an armature coil at the back side of the armature, usually expressed in number of slots.

back ampere turns: The ampere turns on the armature that produce magnetism that opposes that produced by the field coils.

bakelite: A moulded insulating material.

balanced load: Arranging the load equally on the two sides of a three-wire system

balancer coil: An auto transformer used to provide a neutral wire on a 3-wire system

balancer set: Two direct current generators or motors coupled together and used to keep the voltage the same on each side of a 3-wire system.

ballastic galvanometer: A type of galvanometer used for measuring the quantity of electricity suddenly discharged through it, from usually a condenser, expressed as the angle through which the movable part turns.

bank of lamps: A number of lamps, connected either in series or in parallel, used as a resistance.

bank of transformers: A number of transformers located at one place and connected to the same circuit.

bar magnet: A straight permanent magnet.

bar windings: Windings composed of copper bars or rods instead of wire.

barometer: An instrument for measuring the pressure of the atmosphere.

barrier: A partition, slab, or plate of insulating material placed between blades of switches, wires, or conductor in order to separate or insulate them.

battery: A number of similar units arranged to work together. A number of primary or storage cells connected either in series or in parallel.

battery acid: The liquid used in a storage battery. This is usually sulphuric acid.

battery box: The box holding the cells forming the battery.

battery capacity: The amount of energy that can be obtained from a storage battery—usually expressed in ampere-hours.

battery case: A battery box.

battery charger: A rectifier used for changing alternating current into direct current for charging a battery.

battery connector: A lead covered link or bar used to connect one terminal of a cell to the terminal of the next cell of a battery.

battery discharger: An adjustable resistance used to test the condition of the battery by discharging the battery.

battery hydrometer: A hydrometer used for testing the specific gravity or density of the electrolyte in a storage battery.

battery oven: An oven into which storage batteries are placed and heated in order to soften the compound that seals the cover to the battery cells.

battery paint: A paint, that will resist the action of acids, used to paint the battery boxes or battery rooms

battery resistance: The internal resistance of a cell or number of cells. The resistance of the plates and electrolyte measured between the external terminals.

battery steamer: An apparatus used for producing steam inside a storage battery case in order to soften the sealing compound.

bayonet socket: A lamp socket that has two lengthwise slots in the sides of socket and at the bottom the slots make a right angle turn. The lamp base has two pins in it that slide in the slots in the socket. The lamp is held in the socket by being given a slight turn when the pins reach the bottom of the slots.

bearing: That part which holds or supports the shaft.

bearing bracket: That part of the machine extending outward from the frame of a machine and which supports or holds the bearings.

bearing loss: Loss of power due to the friction between the shaft and the bearing of a machine.

bearing metal: A special alloy that has the smallest amount of friction between itself and the rotating shaft. Often used as a lining in the bearing.

bell hanger's bit: A long slim wood bit used to drill through the frame of a building when installing door bells.

bell ringing transformer: A small transformer, slipping the voltage down from 110 volts to about 10 volts, used on a door bell.

B-H curve: A curve that shows the relation between the magnetizing force and the number of lines of force per square inch or centimeter produced in different metals.

Bi: A chemical symbol for bismuth.

bichromate cell: A primary cell consisting of carbon and zinc electrodes immersed in a solution of potassium bichromate and sulphuric acid.

binding posts: Terminals used on apparatus or circuits so that other circuits can be quickly attached.

bipolar: Having only two magnetic poles.

Birmingham wire gauge: Wire gauge used for measuring galvanized iron telephone and telegraph wires; also called Stubs' gauge.

block lead: A form of carbon called graphite.

blow-out coil. An electromagnet used for deflecting the arc between two contacts and thus blowing out the arc.

bond: A short high-grade conductor cable or wire used to connect the end of one rail to the next.

booster: A generator connected in series with a circuit in order to increase the voltage of that circuit.

booster converter: A machine that changes the current from alternating to direct or the opposite, that has a booster built in as part of the machine.

booster transformer: A transformer used to raise the voltage of an alternating current feeder or circuit.

box connector: An attachment used for fastening the ends of cable to a box.

braided wire: A conductor composed of a number of small wires twisted or braided together.

brake shoe: A metallic casting that bears against the wheel in order to stop the wheel from turning.

brake horsepower: The actual power of a machine measured by use of a Prony brake or dynamometer.

branch circuit: That part of the wiring system between the final set of fuses protecting it and the place where the lighting fixtures or drop cords are attached.

branch cutout: The fuse holder for the branch circuit fuse.

brazing: Uniting two metals by a joint composed of a film of brass or alloy that has a higher melting point than solder.

bridge: A Wheatstone bridge.

bridge duplex: A duplex telegraph system dependent for its operation upon the use of a Wheatstone bridge connection in which the telegraph circuit and an artificial line similar to it are the two arms

bridging set: A telephone set designed to be connected in parallel with other telephones to a telephone line.

British thermal unit: The amount of heat required to raise the temperature of one pound of water 1 degree F.

Brown and Sharpe gauge: The gauge used in United States for copper wires. Same as American wire gauge.

bronze: An alloy of copper and tin.

brush: A conductor that makes connection between the rotating and stationary parts of an electrical machine.

brush discharge: A faint glowing discharge at sharp points from a conductor carrying high voltages. It occurs at a voltage slightly less than that required to cause a spark or arc to jump across the gap.

brush holder: The device used to hold or guide the brushes against a commutator or slip ring.

brush holder cable: A stranded conductor composed of a large number of copper wires, smaller in size than those used on regular stranded cables.

brush holder spring: A spring used to press the brush against the commutator or slip ring.

brush holder stud: An insulated bolt or rod to which the brush holders are fastened.

brush lag: The distance that the brushes on a motor are shifted against rotation in order to overcome the effect of armature reaction.

brush lead: The distance that the brushes on a generator are shifted with rotation in order to overcome armature reaction.

brush pig-tail: A short braided wire fastened to the brush. It conducts the current from the brush holder to the brush.

brush rocker: A support for the brush holders and studs arranged so the location of the brushes can be shifted around the commutator.

brush yoke: Iron framework or support for the brush holders.

bucking: One electrical circuit or action opposing another one.

buckling: Warping or twisting of storage battery plates due to too high a rate of charge or discharge.

bulb: The glass inclosing part of an incandescent lamp that surrounds the filament.

Bunsen cell: A primary cell using zinc and graphite electrodes

burn out: Damage to electric machine or conductors caused by a heavy flow of current due to short circuit or grounds.

burning rack: A frame for holding storage battery plates when connectors or straps are being fastened to them.

bus: A contraction for bus bar.

bus bar: The main circuit to which all the generators and feeders in a power station can be connected.

bushing: An insulating tube or sleeve protecting a conductor where it passes through a hole in building or apparatus.

butt joint: A splice or connection formed by putting the ends of two conductors together and joining them by welding, brazing, or soldering.

buzzer: A door bell with the hammer and gong removed.

B-X cable: Trade name for armored cable made by General Electric Co. commonly used to refer to armored cable.

C

C: When used with temperature, refers to centigrade thermometer.

C: Capacity of condenser, usually expressed in farads or microfarads.

Ca: Chemical symbol for calcium.

C.C.W.: Counterclockwise rotation.

Ckt: Circuit.

C.G.S.: Abbreviation for centimeter gram second units—the centimeter being the unit of length, the gram the unit of weight, and the second the unit of time.

C.P.: An abbreviation for constant potential; also for candle-power of a light.

C.W.: Clockwise rotation.

cabinet: Iron box containing fuse, cutouts, and switches.

cable: A conductor composed of a number of wires twisted together.

cable box: A box which protects the connections or splices joining cables of one circuit to another.

cable clamp: A clamp used to fasten cables to their supports.

cable grip: A clamp that grips the cable when it is being pulled into place.

cable rack: A frame for supporting electric cables

cadmium: A silvery white metal.

cadmium test: A test of the condition of the positive and negative plates of a storage battery.

calibrate: To compare the readings of one meter with those of a standard meter that is accurate.

calido: A nickel-chrome electrical resistance wire.

call-bell: An electric bell that tells a person or operator that he is wanted.

calorie: The amount of heat required to raise the temperature of 1 gram of water 1 degree centigrade.

calorizing: A process of coating a metal with a fine deposit of aluminum similar to galvanizing with zinc.

cambric tape: A cotton tape that has been treated with insulating varnish.

candelabra lamp: A small size lamp that has a smaller size screw base than the standard lamp base but larger than the miniature base.

candle: A unit of light intensity.

candle-power: The amount of light for a source as compared to a standard candle.

canopy: The exterior part of a lighting fixture that fits against the wall or ceilings, thus covering the outlet box.

canopy switch: A switch fastened to the canopy and used to turn on and off the light in the fixture

caoutchouc: A crude rubber, known as India rubber.

capacity: Ability to hold or carry an electric charge. The unit of capacity is farad or microfarads.

capacity of a condenser: The quantity of electricity that a condenser can receive or hold.

capacity reactance: The measure of the opposition to the passage of an alternating current through a condenser expressed in ohms.

capillary attraction: The course of the raising and lowering of the liquid in a tube above or below the surrounding liquid.

carbon: A non-metallic element or substance found in graphite, charcoal, coal, and coke.

carbon brush: A block of carbon used to carry the current from the stationary to the rotating part of a machine

carbon contact: A contact made of carbon used where the circuit is opened frequently.

carbon disk: A piece of carbon used as a resistance in a rheostat.

carbon holder: A device for holding and feeding the carbon rods in an arc light.

carbon pile regulator: A number of pieces of carbon arranged as a rheostat to regulate the current to another circuit.

carbon resistance: A resistance formed by carbon plates or powder and arranged so that the pressure on the plates can be varied. The less the pressure, the greater will be the resistance.

carbonize: To turn some other material to carbon by fire

carrier current: A very high frequency current used to provide the energy for transmitting a radio message.

carrying capacity: The amount of current a wire can carry without overheating.

cartridge fuse: A fuse inclosed in an insulating tube in order to confine the arc or vapor when the fuse blows.

case-hardening: The hardening of the outside of metals with heat.

cascade connection: An electrical connection in which the winding of one machine is connected to a different winding of the next machine.

cascade converter: A rotary converter that receives its energy from the rotor (secondary) of an induction connected to the same shaft.

cat whisker: A fine wire spring, one end of which makes contact with a crystal in a crystal radio set.

catenary curve: The curve or sag formed by the weight of a wire hanging freely between two points.

cathion: That part of the electrolyte that tends to be liberated at the terminal when the current leaves the electrolyte.

cathode: The electrode toward which the current flows in an electrolyte. The negative electrode or terminal.

cathode rays: Those rays coming from the cathode of a vacuum tube which produce X-Rays when they strike a solid substance in the tube.

cauterize: The searing or burning of flesh with an electrical heated wire.

C.C.: An abbreviation for cubic centimeter; also **Cu c.m.** is used.

cell: A jar or container holding the plates and electrolyte of one unit of a storage or primary battery.

cell vent: An opening in the cover of a cell which allows the gasses found in the cell to escape.

celluloid: An insulating material made from gun cotton and camphor; it ignites easily and burns up very quickly.

cement: A material used to bind substances together.

cementation: The forming of lead sulphate in small quantities on storage battery plates when they are drying after being made.

center of distribution: A point near the center of the area or section served by a feeder or circuit from a power station or substation. The feeder is usually run directly to this point, and then branches out in all directions from there.

centigrade: A thermometer whose scale is 0 at the freezing point and 100 at the boiling point of water

centimeter: The one-hundredth part of a meter; 0.3937 inches, or longer than ⅜ of an inch.

central: A telephone office or exchange.

central station: A power plant supplying electric light and power to a number of users.

centrifugal cutout: A switch opened by centrifugal force of a rotating body and closed by a spring when the centrifugal force is reduced.

centrifugal force: The force that tends to throw a rotating body, or weight, outward and away from the center of rotation.

chain winding: A type of armature winding which resembles a chain.

characteristic: A curve that shows the ability of a machine to produce certain results under a certain given condition.

charge: That quantity of static electricity stored between the plates of a condenser.

charging: Sending electric current through a storage battery.

charging rate: The number of amperes of current flowing through a storage battery when it is being charged.

choke coil: A coil of a low ohmic resistance and a high inductance which will hold back unusual currents but allow regular steady currents to flow through easily; also reactors or reactance coils.

circuit: The path taken by an electrical current in flowing through a conductor from one terminal of the source of supply to the other.

circuit breaker: A device used to open a circuit automatically.

circular loom: A flexible non-metallic tubing slipped over rubber covered wires for additional insulation and protection.

circular mil: The area of a circle one-thousandth of an inch in diameter; area in circular mils = diameter, in mils, squared or multiplied by itself.

Clark cell: A primary cell that produces a constant voltage for several years and used as a standard source of voltage.

cleat: Piece of insulating material used for fastening wires to flat surfaces.

climber: A sharp steel spur or spike fastened to the shoe and legs of linemen to aid them in climbing poles.

clockwise rotation: Turning in the same direction as the hands of a clock; right-handed rotation.

closed circuit: A complete electric circuit through which current will flow when voltage is applied.

closed circuit battery: Primary cells that will deliver a steady current for a long time A battery that can be used on a closed circuit system.

closed coil armature: The usual armature windings in which the connection of all coils forms a complete or closed circuit.

closed magnetic circuit: A complete magnetic path through iron or other metal without an air gap.

cluster: A lighting fixture having two or more lamps on it.

cobalt: A white metal similar to nickel.

code: A series of long and short sounds given in order to convey certain signals or information.

coefficient of expansion: The increase in length of a rod or body for each degree that the temperature is increased.

coherer: A device used in the early days of radio to detect radio signals.

coil box: A box containing ignition or induction coils.

coil pitch: The number of slots spanned by an armature coil.

collector ring: A metal ring fastened to the rotating part of a machine, and completing the circuit to the rotating part of the machine.

combination fixture: A fixture arranged for both gas and electric lights.

combination switch: A switch on automobiles used to control both lights and ignition.

commercial efficiency: The ratio of total output to input of power.

commutating machines: Generator, motors, and rotary converters that have commutators.

commutating pole: An interpole placed between the pole pieces of a dynamo in order to reduce sparking at the brushes.

commutating pole rectifier: A rotary converter fitted with interpoles.

commutation: Changing the alternating current produced in the armature windings into direct current by use of the commutator and brushes.

commutator: A device by which alternating current produced in a generator is changed into direct current. It consists of a ring made up of a number of copper bars or segments; each bar is insulated from the next one and connected to the end of the armature windings.

commutator bar: A small piece of copper used in building a commutator, a commutator segment.

commutator cement: An insulating substance used in repairing or replacing mica in a commutator.

commutator compound: A compound applied to the surface of a commutator to assist in obtaining a smooth polish.

compass: A small magnetized needle pivoted at the center and pointing in a north and south direction, which is in line with the earth's magnetism, unless influenced by stronger magnets.

compensated machine: A motor or generator with a series field winding placed in slots in the face of the pole piece.

compensated voltmeter: A voltmeter connected with the bus bars at a power station. It indicates the voltage in the feeders, showing the actual pressure furnished at the far end of the circuit.

compensated winding: A winding which is placed in slots cut in the face of the pole pieces parallel with the armature slots. The current in this winding flows in the opposite direction to that in the armature slots.

compensator: A name that is applied to any device which offsets or equalizes in its effect some undesired effect.

component: A part of any thing; used in reference to the analyzing of a current in a circuit by vectors.

composite line: A telephone or telegraph line composed partly of underground and partly of overhead open wires. A line that telegraph and telephone messages may be sent over at the same time.

compound field winding: A winding composed of shunt and series coils either acting together or against each other.

compound generator: A generator that has shunt and series field coils acting together to produce a steady voltage.

compound magnet: A permanent magnet built up from a number of thin magnets of the same shape.

compound motor: A motor that has shunt and series field coils or windings.

concentrated acid: Pure acid that must be diluted before it can be used.

concentric cable: A number of wires wound spirally around and insulated from a central conductor or cable.

condenser: Two conductors separated by an insulating material that is capable of holding an electrical charge.

condenser capacity: The amount of electrical charge that a condenser will hold, measured in microfarads.

condenser dielectric: Insulating material between condenser plates or conductors.

condenser plate: One of the conductors forming the condenser.

condensite: A kind of moulded insulation.

conductance: The ease with which a conductor carries an electric current; it is the opposite of resistance. The unit of conductance is the mho (word "ohm" spelled backward).

conductivity: The ability of a substance to carry an electric current.

conductor: A wire or path through which a current of elecricity flows; that which carries a current of electricity.

conduit: A pipe or tube, made of metal or other material, in which electrical conductors or wires are placed.

conduit box: An iron or steel box located between the ends of the conduit where the wires or cables are spliced.

conduit bushing: A short threaded sleeve fastened to the end of the conduit inside the outlet box. Inside of sleeve is rounded out on one end to prevent injury to the wires.

conduit coupling: A short metal tube threaded on the inside and used to fasten two pieces of conduit end to end.

conduit elbow: A short piece of conduit bent to an angle, usually to 45 or 90 degrees.

conduit rigid: A mild steel tubing used to inclose electric light and power wires.

conduit rod: A short rod which is coupled to other rods and pushed through the large conduit to remove obstructions and pull a cable into the conduit

conduit wiring: Electric light wires placed inside conduit.

condulet: The trade name for a number of conduit fittings made by Crouse-Hinds Co.

connected load: The sum of the rating of all the lamps, motors, heating devices, etc., connected to that circuit.

connecting-up: The process in making splices and connections to complete an electric circuit.

connector: A device used to connect or join one circuit or terminal to another.

connector switch: A device in an automatic telephone exchange that makes connection with the desired line.

consequent pole: A magnetic pole produced by placing together or near each other two north or two south poles. The forming of pole along a magnet as well as at the ends.

consonant: A condition in a transformer which produces resonance in the primary circuit due to a certain combination of capacity and reactance in the secondary circuit. A condition to be avoided except in radio work.

constant current: A current whose amperage is the same all the time.

constant-current circuit: A series circuit, such as a street lighting circuit.

constant-current generator. A generator in which the voltage is increased as the load increases while the current is kept constant.

constant-current motor: A motor designed to operate on a constant-current circuit.

constant - current transformer: A transformer whose secondary delivers a constant alternating current, usually to a series street lighting circuit. The primary is connected to a constant-potential circuit.

constant potential: A constant voltage or pressure in the usual power and light circuit.

constant-potential generator: A generator that produces a constant voltage even though the speed is varying or changing.

constant- potential transformer: A transformer used on a constant-potential circuit.

constant-speed motor: A motor that runs at the same speed when carrying a full load as when lightly loaded.

constant-voltage regulator: A regulator that causes a generator to produce a steady voltage at varying loads.

contact: A place where a circuit is completed by a metallic point being pressed against a conductor. When the pressure is removed, the circuit is opened and flow of current stopped.

contact drop: The voltage drop across the terminals of a contact.

contact resistance: The resistance in ohms across the contact points.

contact sparking: The spark or arc formed at the contact points when a circuit carrying current is opened.

contactor: A device used to open and close an electrical circuit rapidly and often.

continental code: A series of dot and dash signals generally used in radio work to send telegraph messages.

continuous current: A direct current that is free from pulsations.

continuous rating: The output at which a machine can operate continuously without overheating or exceeding a certain temperature.

contractor: One who agrees to do a certain job for a sum of money agreed upon before the work is started.

control switch: A small switch used to open and close a circuit which operates a motor or an electromagnet coil. This motor or electromagnet is used to operate or control some electric machine.

controller: A device that governs or controls the action of electrical machines connected to it.

controller resistance: The resistance used with a controller to start and vary the speed of the motor.

converter: A machine that changes electric current of one kind into current of another kind by the use of rotating parts.

conveyors: Mechanical devices used to carry material from one place to another.

Coolidge tube: An X-ray tube first developed by Wm. D. Coolidge.

copper: A metal used for electrical conductors because it has less resistance than any other metal except silver.

copper bath: An electrolyte composed of copper salts or crystals used for copper plating.

copper clad: Iron or steel wire covered with a layer of copper in order to increase the conductivity.

copper loss: The I^2R loss in power due to the resistance of the copper conductors or wires.

copper plating: Depositing a layer of copper or other metals by the electroplating process.

copper ribbon: A thin bar or strip of copper.

copper strip: A long thin bar of copper, usually about 1/16 to 3/8 of an inch thick.

cord: Two insulated flexible wires or cables twisted or held together with a covering of rubber, tape, or braid.

core: The iron or steel in the center of a coil through which magnetic lines of force pass

core iron: Iron sheets used for making cores of magnets, transformers, generators, and motors.

core loss: The power lost in a machine due to eddy currents and hysteresis losses.

core transformer: A transformer with the windings placed on the outside of the core.

corona: A violet light glow that occurs on high voltage conductors just before the voltage becomes high enough to cause a spark or arc.

corrosion: The rusting of iron and a similar action and deposit formed on other metals.

cotton-covered wire: A wire covered with a layer of thin cotton threads wound spirally around it.

cotton-enameled wire: An enameled insulated wire covered with a layer of cotton threads.

cotton sleeving: A woven cotton sleeve or tube slipped over wires to insulate them.

coulomb: The quantity of electricity passing through a circuit. It is equal to amperes times seconds. An ampere hour = 3600 coulombs.

counter-clockwise rotation: Turning left handed, which is in a direction opposite to that of the hands of a clock.

counter-electromotive force: The voltage or pressure that opposes the normal voltage tending to force a current through a circuit.

cowl lamp: A lamp placed on the dashboard of an automobile to light the instruments on it.

creeping of wattmeter: A slow turning of the wattmeter disk when there is no power passing through it.

Crookes' tubes: Tubes used for producing X-rays.

cross arm: An arm fastened at the top of the pole to support the wires.

cross magnetization: The magnetic lines of force produced in the armature that are at right angles to those produced by field coils.

cross over: A device that enables one wire to cross over another or a car to pass from one track to another parallel one.

cross-section area: The surface of the end of a wire, rod, or other object. It is measured in square inches, square centimeters, square mills, etc.

crow foot: A small fitting fastened in an outlet box to which fixtures are fastened.

crow-foot zinc: A zinc plate having extending arms, used in a gravity cell.

current: The flow of electricity through a circuit.

current coil: The coil or winding through which the current in a circuit flows.

current density: The number of amperes per square centimeter or square inch of cross sectional area of the conductor.

current regulator: A device that regulates or limits the flow of current through a circuit.

current strength: The flow of current in amperes.

current transformer: A transformer in which the flow of current in the secondary winding is in proportion to that flowing through the primary circuit, also called series transformer.

cut-in: A device operating in an electric circuit which connects two circuits together.

cut-out: A device that opens or disconnects one circuit from another.

cut-out box: The box in which fuse holder blocks, and fuses are located.

cycle: The flow of alternating current first in one direction and then in the opposite direction in one cycle. This occurs 60 times every second in a 60-cycle circuit.

D

D.C.: Used as an abbreviation for "direct current." Used as an abbreviation for "double contact."

D.C.C.: Used as an abbreviation for "double cotton-covered wire."

D.P.: Used as an abbreviation for "double pole."

D.P.S.: Used as an abbreviation for "double pole snap switch."

D.P.S.T.: Used as an abbreviation for "double pole single throw."

D.P.D.T.: Used as an abbreviation for "double pole double throw."

damper winding: As applied to copper pieces so placed in the pole faces of alternating-current machines as to reduce hunting

damping: Causes the needle of an electric measuring instrument to come to rest quickly.

damping coil: Used to cause the needle of a galvanometer to quickly return to zero

damping magnet: Any magnet used to check the motions of a moving object or magnet.

Daniel cell: A primary electric cell, using copper and zinc for electrodes, used on closed circuit work.

D'Arsonval meter: A voltmeter or ammeter whose pointer is attached to a moving coil of fine wire carried between the poles of a permanent magnet.

dashboard instruments: Ammeter, voltmeter, or current indicator, suitable for mounting on the dashboard or cowl board of an automobile.

dash pot: A cylindrical chamber containing oil, air, or other fluid in which moves a plunger attached to some part in which it is desired to avoid sudden changes of position.

dead beat: An instrument whose pointer comes immediately to its true reading without swinging back and forth.

dead coil: An armature coil which is not connected in the armature circuit of the windings but which is required in order that there may be the proper number of coil sides in each slot.

dead end: The end of a wire to which no electrical connection is made. The end used for supporting the wire. The part of a coil or winding that is not in use.

dead end eye: A metal eye threaded at one end to attach to a rod and holding a cable in the loop of the

dead ground: An accidental ground of low resistance through which most of the current can escape from a circuit.

dead man: A short pole with crossarms to which the guy wire from another pole is fastened.

dead wire: A wire in which there is no electric current or voltage.

decade bridge: A Wheatstone bridge having ten separate coils of equal resistance value.

deci: Is a term meaning one-tenth.

deci-ampere: One-tenth of an ampere.

declination: The difference between the position of a compass needle and the true position of geographical north and south.

declinometer: An instrument for measuring the declination of a compass needle.

de-energize: To stop current from flowing in a circuit or an electrical part.

deflection: The movement of the indicating pointer of an electric measuring instrument.

deflection of compass needle: The movement of a needle from a point of repose either in the earth's magnetic field or in that of another magnet and produced by the influence of the flux of an electric current or of a magnet

deka: A prefix meaning ten times.

deka ampere: Ten amperes.

delivered power: The power delivered at one end of a line, in a system of electrical transmission in contradistinction to the power delivered into the line at the other end.

delta connection: Series hookup of three circuits of an alternator, the end of one circuit being connected to the beginning of the next, etc. The wiring diagram of this arrangement resembles a triangle or the letter Delta of the Greek alphabet

demagnetization: Process of removing the magnetism from a magnetized substance. This may be done either by heating to a red heat, by violent jarring, or by holding the magnetized substance in and then gradually removing it from the magnetic field of a solenoid operated on an alternating current.

demagnetizing armature turns: Inductors of an armature, which, while moving in the field of the poles, set up a counter-magnetic field that tends to demagnetize the poles.

demand: Amount of electric current needed from a circuit or generator.

demand factor: Ratio of the maximum amount of current consumed in one sub-circuit to the total load or current draw on the whole circuit.

demand meter: Device which registers the maximum ampere consumption of appreciable duration in a circuit.

density: The ratio of a quantity of a substance to the space it occupies; i.e., the ratio of mass to volume.

density of current: Amount of current flowing through a conductor of given cross-sectional area.

density of field: Amount of magnetic flux, or lines of force, contained in a given cross-sectional area.

density of electrolyte: The proportion of chemical in the water with which it is mixed to make an electrolyte. See "specific gravity."

depolarize: (a) To eliminate or retard the gas which tends to collect on the electrodes of an electric cell when it is being charged or discharged. (b) Synonym for demagnetize.

depolarizer: A chemical, electrochemical, or mechanical agent introduced into the cell to prevent or retard the formation of gas which polarizes the electrodes.

derived circuit: Shunt or parallel circuit, the current for which is obtained from another circuit.

deviation factor: Difference between an alternating-current wave of a generator and a true sine wave.

diamagnetic substance: One that is repelled by a magnet, as bismuth and phosphorus.

diaphragm: A disk or sheet of metal or other substance having enough flexibility to vibrate, as a telephone-receiver diaphragm.

dielectric: Insulation between conductors of opposite polarity; term generally used only when induction may take place through it.

dielectric constant: A number representing the dielectric quality of a given substance as compared to that of air.

dielectric current: Leakage of current through a dielectric.

dielectric hysteresis: Consumption of energy caused by molecular friction in a dielectric under changes of electrostatic pressure.

dielectric resistance: Resistance of a dielectric to electrical pressure.

dielectric strain: Strain to which a dielectric is subjected while it is under electrical pressure.

dielectric strength: Ability of a dielectric to withstand electrical pressure before breaking down. This is measured in volts necessary to puncture the dielectric.

dies (pipe): Tools for cutting and threading metal conduit.

difference of potential: Difference in voltage between two conductors or two points along one conductor carrying an electric current.

differential booster: Generator in a battery-charging arrangement to maintain a constant voltage

differential electromagnet: An electromagnet having part of its winding reversed to oppose the other part to permit adjustment of the pull.

differential field winding: Field winding in which the shunt and series windings of a compound-wound motor or generator oppose each other.

differential galvanometer: Galvanometer having two coils wound to counteract each other.

differential generator: Generator in which the shunt and series field windings counteract each other to limit the maximum amperage.

differential motor: A direct-current motor having its shunt and series field windings opposing each other, to obtain a constant speed.

differential relay: A relay consisting of a differential electromagnet.

differential winding: Coil which is wound opposite to another to counteract it.

diffusion of magnetic flux: Deviation of the magnetic lines of force from a straight path between the poles.

dimmer: A resistance coil connected in series with a lamp to reduce the amount of current flowing through it, and consequently to dim or reduce the light.

dinkey: Small, two-wheeled cart used for hauling poles in line construction.

dip: Angle which a magnetic needle, pivoted in a vertical plane, makes with the horizontal.

dipping needle: Magnetized needle pivoted freely at its center of gravity in a vertical plane so that, when set in a magnetic meridian, it dips until it lies parallel to the magnetic lines of force of the earth.

diphase generator: Generator producing two alternating currents a quarter of a cycle apart.

diplex telegraphy: Transmission of two telegraphic messages over the same wire, at the same time, and in the same direction.

direct-connected: Two electrical machines, such as a motor and a generator, connected together mechanically and in line, by having their shafts coupled together or by both being mounted on the same shaft.

direct current: Electric current flowing over a conductor in one direction only. Abbreviation d.c.

direct-current convertor: Device for changing a direct current of one potential to a direct current of another potential.

direct-current generator: Generator that delivers direct current.

direct-current instrument: Device operated on direct current.

direct-current magnet: Electromagnet operated on direct current.

direct-reading galvanometer: A galvanometer provided with a scale so calibrated that the current flow may be read directly, without the necessity of calculating it from the proportions of the coil and the magnetic moment of the needle.

disc armature: Armature of a generator consisting of a flat disc on which the coils are mounted.

discharge: Removal of electricity from its source through a circuit.

discharge recorder: Device which detects and records discharges through a lightning arrestor.

discharge resistance: Resistance coil which is connected across a circuit breaker to prevent arcing when the contacts separate.

discharger: Resistance device which is connected across the terminals of a storage battery to discharge it slowly without damaging it.

disconnect: To remove an electrical device from a circuit, or to unfasten a wire, making part or all of the circuit inoperative. The word is particularly applied to the act of severing a telephone connection to permit repairs.

disconnector: Switch for cutting out circuits having high voltages, done only under a minimum load.

displacement current: Small current of electricity in a dielectric which is under strain of a high potential.

disruptive discharge: Violent discharge of electricity accompanied by a spark.

dissonance: Lack of consonance or agreement; as of alternating currents of opposite phase.

dissociation: Separation of the component elements of a chemical mixture or compound, without the aid of any other chemical agency.

distortion of field: A condition causing magnetic flux between the poles of a magnet to assume an arched or curved path instead of a straight one from pole to pole.

distribution box: Small metal box in a conduit installation, giving accessibility for connecting branch circuits.

distributing frame: Structure where connections are made between the inside and outside wires of a telephone exchange.

distribution: Division of current between the branches of an electrical circuit.

distribution lines: The main feed line of a circuit to which branch circuits are connected.

distribution center: Point along the main feed lines which is approximately in the center of the branch lines.

distribution panel: Insulated board from which connections are made between the main feed lines and branch lines.

distribution system: The whole circuit and all of its branches which supply electricity to consumers.

distributive: Tending or serving to distribute.

divided circuits: Approximate division of a distribution system to balance both sides of the lines. A divided magnetic circuit is one having more than one path through which the flux passes.

dome lamp: Small lamp attached to the underside of the top of an automobile.

door lamp: Small lamp for lighting the doorway and running board of an automobile.

door lantern: Lamp hung so as to illuminate the entrance of a house.

door opener: Motor-driven device for opening and closing garage doors.

door switch: Switch which is operated by opening and closing the door to which it is connected.

double armature: An armature which has two separate windings on one core.

double-break switch: Switch which connects and disconnects two contacts at the same time.

double-contact lamp: Lamp with a base having two terminals to which electrical contact is made when it is inserted in a socket.

double-cotton-covered: Wire covered with two layers of cotton insulation. Abbreviation d.c.c.

double-current generator: A generator delivering both direct and alternating current.

double deck: Arrangement of two electrical machines, one mounted above the other.

double delta connection: Connection of three transformers by which a 3-phase system is connected to a 6-phase system.

double-filament lamp: Lamp having two separate filaments of different resistances to provide low and high brilliancy.

double-pole: A term designating two contacts or connections on a device, for instance, a double-pole knife switch. Abbreviation d.p.

double reduction: Speed reduction in a machine obtained by using two sets of gears or pulleys.

double-silk-covered. Wire covered with two layers of silk insulation Abbreviation d.s.c.

double-throw switch: Switch which can be operated by making contact with two circuits. Abbreviation d.t.

double trolley: Street-railway system using two overhead trolleys instead of one, carrying the positive and negative current. This arrangement eliminates electrolysis caused by grounding one conductor, but it increases trolley troubles, and for this reason is seldom used.

double re-entrant winding: Armature winding, half the conductors of which make a closed circuit.

draft: Air drawn or forced up into the fire-box to accelerate fuel combustion.

draft tube: Tube or passage through which the discharge from a hydraulic turbine flows into the tailrace.

draw bar: Bar on a locomotive which is used to connect it to a train.

draw-bar pull: Force available at the draw bar of a locomotive to pull a train, as distinguished from the actual power of the engine or motor.

drive shaft: Shaft employed to drive a number of machines. Line shaft.

driven pulley: A pulley to which movement is imparted by means of a belt from another pulley.

driving pulley: Pulley that drives another through the medium of a belt.

drop: Usual term for drop of potential.

drop annunciator: Annunciator having one or more electromagnets, each of which, when operated, releases a catch holding a small plate or shutter, and allows it to drop, exposing a number or letter.

drop of potential or voltage: Decrease of voltage at points along a circuit, caused by resistance.

drop wire: Wire which is connected to a feed wire outside of a building, and brings the supply inside.

drum: The laminated iron cylinder or core of an armature for a generator or motor.

dry battery: A number of dry cells connected together in series or parallel to obtain more voltage or amperage, respectively.

dry cell: A primary source of electric current consisting of three elements; a zinc cylinder, a paste electrolyte and a carbon rod or electrode. The zinc cylinder is filled with the electrolyte and the carbon electrode is placed in the center but not touching the zinc; the top of the cell is sealed with a wax compound. The chemical action of the electrolyte on the zinc sets up an electric current when the cell is connected to a current-consuming device, as a bell. The carbon electrode is the positive and the zinc is the negative.

dry storage: Method of keeping a storage battery, when not in use, by removing the electrolyte.

dual ignition: Ignition system for an internal combustion engine which may obtain current from either a battery or a magneto as desired.

dual magneto: Ignition magneto which has its armature wound so that it can deliver both its own current and that of a battery to the distributor.

duct: (a) A space in an underground conduit to hold a cable or conductor. (b) A ventilating passage for cooling an electrical machine.

duct-foot: Unit expressing the total length of all the cableways in one lineal foot of an underground conduit. Thus, a 6-duct conduit, one foot long, contains 6 duct feet

duo-lateral coils: Form of honeycomb inductance coils used in radio, which are designed to reduce the distributed capacity.

duplex cable: Cable consisting of two wires insulated from each other and having a common insulation covering both.

duplex ignition: Ignition system capable of sending both the battery and the magneto current into the induction coil at the same time.

duplex telegraphy: Telegraph circuit permitting the transmission of two messages in opposite directions at the same time over a single wire.

duplex winding: Two separate windings on the same armature or coil.

duplex wire: Same as duplex cable.

dynamic braking: Method of stopping a motor quickly without the aid of a mechanical brake. On d.c. a resistor connected across the armature stores the electrical energy produced by the motor which acts as a generator when the line circuit is broken. On polyphase a.c. motors this method of braking is obtained by energizing one phase winding with direct current.

dynamic electricity: Electricity in motion as distinguished from static electricity.

dynamo: A synonym for generator; formerly applied to both motor and generator, although modern use tends to confine its meaning to d.c. generators.

dynamometer: Mechanical or electrical device for measuring the torque of a machine in order to determine its power output.

dynamotor: Electrical machine which acts as both motor and generator, running on and producing either direct or alternating current. It has one field and two separate armatures or a double-wound armature.

dyne: Unit of force. Power or force required to cause an acceleration of one centimeter per second to a mass of one gram.

E

E: Symbol for volts.

EBB: Abbreviation for "extra best best" iron wire used for telephone and telegraphic purposes.

E.C.&M.: Trade name for electric-control equipment, lifting magnets, etc.

E.H.P.: Abbreviation for electrical horsepower.

E.M.F.: Abbreviation for electromotive force.

E.P.C.: Abbreviation for Electric Power Club.

ear: Device for supporting a trolley line; a bronze casting grooved to receive the trolley and having lips which are clinched around it. The ear is supported on a trolley hanger.

earth: Synonym of "ground," meaning the grounded side of an electrical circuit or machine.

earth current: Current passing through the ground.

ebonite: Substance consisting of black hard rubber and sulphur. It is hard and brittle, has high insulating qualities, and possesses inductive qualities to a high degree.

economiser: Device used on boilers to absorb the heat that has passed the flues and would be wasted out of the stack; used to preheat boiler feed water.

eddy-current loss: Loss of energy of an electrical machine which is caused by eddy currents.

eddy currents: Currents in armatures, pole pieces, and magnetic cores, induced by changing electromotive force. It is wasted energy and creates heat.

Edison battery: Storage battery having plates made of nickel peroxide and iron, and using potassium hydrate and water for an electrolyte.

Edison distributing box: Box used in three-way distribution systems.

Edison-Lalande cell: Primary electric cell having electrodes made of copper oxide and zinc and using a caustic soda solution as an electrolyte.

"Ediswan" or bayonet socket: Lamp socket having a bayonet base, which is popular on automobile-lighting systems, and is used for house lighting in England.

"Ediswan" connector: Plug connector having a base similar to that of an "Ediswan" socket.

effective current: Value of a current as shown on a steady-reading ammeter.

effective electromotive force: Difference between the impressed and the counter e.m.f.

effective resistance: All electrical and inductive losses of a current.

efficiency: The ratio of the amount of power or work obtained from a machine and the amount of power used to operate it.

elastance: Inability or opposition to retaining an electrostatic charge. Opposite to capacity.

elastivity: Specific elastance of a substance.

elbow: Hollow fixture for connecting two lengths of conduit at an angle, usually fitted with a removable cap to facilitate drawing the wires through one conduit and then inserting them in the other one.

Electragist: Term used by the National Association of Electrical Contractors and Dealers, now the Association of Electragists, to denote a person conducting an electrical-contracting business.

electric or electrical: Pertaining to electricity.

electric circuit: Path through which an electric current flows.

electric breeze or wind: Emission of negative electricity from a sharp point of a conductor carrying a high potential.

electric candle: Small electric arc lamp.

electric charge: Quantity of electricity on a conductor.

electric eel: An eel found in South American waters which is capable of giving off painful and dangerous shocks of high potential, estimated equal to the combined charge of 15 Leyden jars, each having 1 2/3 square feet of tinfoil coating.

electric energy: Power of electricity to perform work, mechanically or in the production of heat and light.

electric furnace: Furnace using electricity to produce heat.

electric glow: electrostatic discharge causing a violet light around conductors carrying high potentials, occurring just before the emission of a spark or a steady brush discharge.

electric heater: Heater consisting of resistance wire which becomes hot as the current flows through it.

electric horsepower: The equivalent of one horsepower in electrical energy, which is 746 watts.

electric potential: Pressure or voltage of electricity.

electric power plant: Installation consisting of a prime mover driving a generator to produce electricity.

electric spectrum: The component colors of an electric arc separated by means of a glass prism.

electric units: Standards of measurement of electrical properties; for instance, ampere, volt, ohm, farad, henry, etc.

electric wave: Theoretical form of movement of an electric current transmitted through air.

electric welding: Process of welding with the use of an electric arc or with heat generated by current flowing through the resistance of the work to be welded.

electrical codes: Rules and regulations for the installation and operation of electrical devices and currents.

electrical series: A list of substances which, when two are rubbed together, will produce an electrostatic charge, as silk and hard rubber.

electrical sheet: Steel or iron sheets from which laminations for electrical machines are punched.

Electrician: Person working or experimenting with electrical devices.

electricity: Invisible energy capable of moving 186,000 miles per second. Electricity is really not capable of being defined exactly, with present knowledge.

electrification: (a) Providing means to operate devices with electricity. (b) To impose a static charge.

Electrochemical: Pertaining to the interaction of certain chemicals and electricity, the production of electricity by chemical changes, the effect of electricity upon chemicals, etc.

electrochemistry: Science of electrochemical interaction.

electrodynamic: Pertaining to electricity in action.

electrodynamometer: Device for measuring the strength of an electric current by its attraction or repulsion to conductors carrying current.

electrocute: (a) To execute a criminal by electricity. (b) Persons accidentally killed by electricity are said to be electrocuted.

electrode: Either terminal of an electric source, particularly an electric cell. Also applied to the terminals of electrical apparatus applied to the human body in the treatment of disease.

electrokinetic: Pertaining to electricity in action.

electrolier: Hanging electric fixture holding lamps which can be lighted separately or all at once.

electrolier switch: Switch which controls the lamps of an electrolier.

electrolysis: Chemical decomposition caused by an electric current.

electrolyte: Chemical solution used in an electrical device which passes an electric current.

electrolytic: Pertaining to electrolysis.

electrolytic condenser: Condenser using an electrolyte as a dielectric.

electrolytic decomposition: Separation of the elements in an electrolyte.

electrolytic generator: Generator for charging storage batteries.

electrolytic interrupter: Device for rapidly interrupting or breaking up a direct current into pulsations, consisting of a cathode, generally a lead plate, immersed in a dilute solution of sulphuric acid, and an anode, which is a small platinum wire projecting into the electrolyte from a porcelain tube. Often called a Wehnelt interrupter after the inventor.

electrolytic lightning arrestor: Lightning arrestor consisting of an electrolyte, which covers two electrodes immersed in it with a film. This breaks down under a lightning discharge.

electrolytic rectifier: Device for changing an alternating current to a direct current by passing it through an electrolyte in which electrodes are immersed. The device acts as a "valve" to allow current to pass in one direction only.

electromagnet: Soft iron core having a coil wound around it through which an electric current is passed. The core is magnetized while the current flows, but is demagnetized when the current stops.

electromagnetic attraction: Attraction between opposite poles of an electromagnet.

electromagnetic brake: Brake used on car wheels and operated by electromagnets.

electromagnetic field: Space around a conductor or instrument, traversed by the electromagnetic waves set up by current in the conductor.

electromagnetic induction: Electric current set up in a conductor cutting the field of flux of an electromagnet.

electromagnetic repulsion: Repulsion between like poles of an electromagnet.

electromagnetic unit: Unit or standard of measurement of electromagnetic effects.

electromagnetic vibrator: Mechanical interrupter operated by an electromagnet.

electromagnetic wave: Form of electromagnetic energy radiated from a conductor and theoretically assuming the form of a wave. The rate of travel of these waves is approximately 186,000 miles per second.

electromagnetism: Science dealing with electricity and magnetism and their interaction.

electrometallurgy: Branch of metallurgy dealing with the use of electric currents either for electrolytic separation and deposition of metals from solutions, or with the utilization of electricity for smelting, refining, welding, annealing, etc.

electrometer: Device for measuring small voltages.

electromotive force: Electrical pressure or voltage which forces an electric current through a circuit.

electron: Electrical particle, of negative polarity.

electron theory: Theory that all matter consists of atoms which in turn comprise a positive nucleus and a number of negative electrons, which may be detached from the atom under certain conditions, leaving it positively charged.

electro-negative: Having a negative polarity.

electropathy: Science dealing with the use of electricity for medical purposes.

electrophorous: Device consisting of a disc of ebonite or similar substance, a metal plate and an insulator, used to produce an electric charge by induction.

electroplasm: Science dealing with the stimulation of vegetable growth by means of electricity.

electroplating: Process of covering a metal article with a metal deposit taken from an electrode and conveyed by an electrolyte in which the article is submerged.

electro-positive: Having a positive electrical polarity.

electro-receptive device: Device that receives electricity for its operation.

electroscope: Device that indicates the presence of a very small charge of electricity. It consists of a glass bottle having an electrode, which holds two strips of light foil. These attract or repel each other, depending upon the nature of the charge.

electrostatic: Pertaining to static electricity, or electricity at rest.

electrostatic capacity: Capacity to hold an electric charge, which is measured in farads and microfarads.

electrostatic field: Range around conductors, electrical machines and instruments where electrostatic effects take place.

electrostatic galvanometer: Galvanometer operated by the effect of two electric charges on each other.

electrostatic machine: Device which produces high-potential charges of static electricity by means o. friction.

electrotherapeutics: Science dealing with the use of electric currents for curing diseases.

electrothermal: Pertaining to the heating effect of electric currents, and to electric currents produced by heat, as in thermo-couple.

electrotype: Metal plate used for printing. It is made by depositing metal on a form by means of electroplating.

element: (a) One of the parts to which all matter can be reduced. (b) One of the parts constituting a device, as a radio-tube element. (c) The resistor of an electrical heating device.

elevator cable: Flexible cable conveying electricity to an elevator. Also one of the cables supporting an elevator.

"Elexit": Trade name for certain standardized interchangeable fixture receptacles and plugs.

emissivity: Rate at which particles of electricity or heat are radiated from an object.

empire cloth: Cotton or linen cloth coated with linseed oil, and used as an insulator.

enameled wire: Wire having a coating or enamel baked on, which serves as insulation.

enclosed fuse: Fuse inside of a glass tube to prevent ignition of gas or dust.

end cell: One of a number of cells at the end of a storage battery, which can be cut in or out of the circuit to regulate the voltage.

end play: Distance of movement of a shaft in line with its length.

end thrust: Thrust exerted in line with the length of a shaft.

Endosmosis: The flow of a thin liquid to a denser liquid through a permeable partition. See "osmosis."

energize: To put energy into; e.g., magnetizing an iron core of an electromagnet by passing a current through the coil.

energy: Capacity for performing work.

entrance switch: Switch to which the wires entering a building are connected.

equalizer: Connection between generators in parallel to equalize their voltage and current.

equalizing charge: Slight overcharge on a storage battery to raise the reading of the cells having the lowest specific gravity.

equator of magnet: Position halfway between the opposite poles of a magnet.

equipotential: Having the same potential.

equilibrium: State of rest or balance between two opposite forces, produced by their counter-action.

ether: Hypothetical element filling space to permit the passage of heat, light, electricity, gravity, etc., between solar bodies.

Evaporator: Heating device for evaporating water.

excite: To send a current through the field windings of a generator to set up a magnetic flux.

exciter: Small battery of generator furnishing current for the field windings of a large generator.

exciting current: Current which passes through the field windings of a generator.

extension: Length of cable or lamp-cord fitted with a plug and a socket to extend a lamp or other electric device further than the original point.

exploring coil: Device used for the detection of faults in underground cables. It consists of a coil and telephone receiver or head set, a current being induced in the coil at the point of leakage and causing a noise in the receiver. (b) Coil used to locate underground metals.

"Extra Best Best" iron wire: Trade name for the highest grade iron telegraph and telephone wire. Abbreviation EBB.

external circuit: A circuit entirely outside of the source of supply.

F: Abbreviation for frequency.

Fabrikoid: Trade name for a substitute for leather.

factor: Any one of the elements that contribute to produce a result.

factor of safety: Multiplier used in machine and structure design, designating the overload or safety capacity. E.g., a pressure vessel designed to withstand a pressure of 10 pounds per square inch may actually withstand 50 pounds per square inch, and the factor of safety is 5.

fading: Temporary diminution of signal strength in radio reception, due to atmospheric conditions.

Fahrenheit: A thermometer scale so graduated that the freezing point of water is 32° and its boiling point is 212°.

fall of potential: Drop in voltage between two points of an electric circuit.

false resistance: Resistance of counter e.m.f.

fan motor: Motor operating a fan.

farad: Unit for measuring electrical capacity. It is the capacity of a condenser which will give a pressure of one volt when a one-ampere current flows into it for one second.

farm-lighting generator: Small, gasoline-driven generator, producing current for farm light and power; usually a 32-volt and 2 or 3 kilowatt unit.

fathom: Nautical measure of length, equal to 6 feet. This unit is used to measure cables.

fault: Trouble in an electrical circuit.

fault finder: A resistance bridge for locating faults in telephone and telephone circuits.

fault resistance: Resistance caused by a fault.

Fauré plate: Storage-battery plate consisting of a lead grid filled with paste.

feeder: Line supplying all the branch circuits with the main supply of current.

feeder box: Box into which the feeder is run for connection to a branch circuit.

fender: Device attached to street cars and other vehicles to pick up or brush aside obstacles.

ferro-manganese: Containing iron and manganese.

ferro-nickel: Containing iron and nickel.

fibre: A hard, tough insulating substance.

fibre cleats: Cleats made of fibre, used for holding conductors on flat surfaces.

fibre conduit: Insulating tubing made of moulded fibre.

field: Space occupied by the flux of a magnet.

field coil: Coil or winding around the field magnets of a generator or motor.

field discharge resistance: A resistance coil connected across the field winding of a generator permitting the winding to be discharged without a dangerous rise in voltage when the field circuit is opened by a switch. It is usually connected to a special d.p.d.t. knife switch having an auxiliary blade which connects the resistance just before the current to the winding is cut off.

field distortion: Variation of magnetic flux from the straight path between opposite poles in a generator, which is caused by armature reaction.

field flux: Space occupied by the lines of force of a generator field.

field intensity: Density of the field flux of a generator.

field magnet: The iron parts of a generator frame through which the flux of the coils concentrates.

field rheostat: A variable resistance device connected in the field circuit to control the voltage of a generator and the speed of a motor.

field winding: Coil on a field pole of a generator.

filament: Small wire in a lamp, which becomes white hot when electric current is passed through it.

film cutout: Insulating film between the two opposite wires inside of a lamp. The film burns out when the filament breaks and this permits the two wires to make contact, which provides a path for the current so that it can flow to other lamps, connected in series. These will not light unless the current passes through the defective lamp.

filters: Devices having inductance and capacity, and designed to suppress certain electrical frequencies.

fire-alarm systems: Apparatus which gives alarm in case of fire. Some of these systems consist of electrical circuits which, when closed automatically or otherwise, sound the alarm.

fire extinguisher: Devices using a liquid or powder to extinguish fire. They are used in power houses where there is danger of burning insulation on cables. Fire extinguishers used for this purpose must contain non-conducting liquids such as carbon tetrachlorid.

fish paper: Strong paper used for insulation.

fish wire: Flat, narrow, flexible, steel wire which is used to pull conductors through lengths of conduit.

fixed resistance: Non-Adjustable resistance.

fixture: Device for holding electric lamps, which is wired inside and is securely attached to the wall or ceiling.

fixture wire: Insulated, stranded wire used for wiring fixtures.

flaming arc: Arc which gives different colors due to impregnating the carbons with various salts and minerals.

flaming of arc: A flame bridging the gap between two carbons, instead of a steady arc, caused by the carbons being too far apart.

flasher: Automatic or motor-driven switch or series of switches for lighting electric signs intermittently.

flashing over: Passage of sparks from commutator segments traveling away from the brush, to the edge of the brush, which is then touching a segment adjacent to the one from which the spark originates.

flashlight: (a) Small, portable, electric light operated on one or more dry cells. (b) Trade name for an electric alarm clock.

flat-compound generator: Compound-wound generator having windings which give a constant voltage under different loads and speeds.

Fleming's rules: Rules for finding the direction of a conductor's motion through a magnetic field, the direction of the lines of force, and the direction of current flow through a conductor, applicable to direct current. Rule for Generators: Hold the thumb, the index finger, and the middle finger of the right hand so that they are at right angles to each other. The thumb will then point in the direction of the motion of the conductor, the index finger will point in the direction of the lines of force, and the middle finger will point in the direction of the current through the conductor. Rule for Motors: Hold the thumb, the index finger, and the middle finger of the left hand at right angles to each other. The thumb will then point in the direction of the motion of the conductor, the index finger will point in the direction of the lines of force, and the middle finger will point in the direction of current through the conductor.

flexible cable: Cable consisting of insulated, stranded or woven conductors.

flexible conduit: Non-rigid conduit made of fabric or metal strip wound spirally.

flexible cord: Insulated conductor consisting of stranded wire.

floating battery: Storage battery connected in parallel with a generator and the load, so that the battery will consume the surplus current from the generator if the load is small, and will supply additional current if the load exceeds the output of the generator.

flood lights: Battery of lamps of high brilliancy, equipped with reflectors to supply a strong light.

flow: Passage of a current through a conductor.

fluctuating current: Current which changes in voltage and amperage at irregular intervals.

flush receptacle. Type of lamp socket, the top of which is flush with the wall into which the socket is recessed.

flush switch: Push-button or key switch, the top of which is flush with the wall into which it is recessed.

flux: Magnetic lines of force existing between two opposite magnetic poles.

flux density: Number of lines of force in a given cross-sectional area, which is measured in gausses.

focus: The point where rays of light, heat, sound, etc., meet after being reflected or refracted.

foot candle: See "candle foot."

foot-pound: Unit for measuring work. It is the energy required to raise a weight of one pound through a distance of one foot.

force: Energy exerted between two or more bodies which tends to change their relative shape or position.

form factor: Ratio of effective value of one half of a cycle of an alternating current to the average value of similar half cycles.

formers: Forms used for producing a number of windings of the same shape.

form-wound coils: Coils or windings built up on formers before they are placed in their proper position on armatures, field poles, etc.

forming battery plates: Passing an alternating current through a storage battery to deposit peroxide of lead and spongy lead on the plates, which makes them active.

Foucault currents: Same as Eddy currents.

four-pole: (a) Having four poles, as in a generator. (b) Having four contacts, as in a four-pole switch.

four-way switch: Switch that controls the current in four conductors by making or breaking four separate contacts.

four-wire, three-phase system: Distribution system having a 3-phase star connection, one lead being taken from the end of each winding and the fourth from the point where they are all connected together.

fractional pitch: Term used when the number of slots between the sides of an armature coil is not equal to the number of slots of each pole.

franchise: Permit from municipal, state, or national government to use public property, such as streets, for special purposes, as the installation of street-car lines.

frequency: Number of cycles or vibrations per second.

frequency changer: Motor-generator driven by an alternating current of one frequency and delivering current of another frequency.

frequency convertor: Same as "frequency changer."

frequency indicator: Device showing when two alternating currents are in phase or have the same frequency.

frequency meter: Device showing the frequency of an alternating current.

friction tape: Tape coated with black adhesive compound, used as insulation on wire joints, etc.

frog: Fixture for street-car tracks or trolleys where one track or trolley branches off, permitting the car to be run from one track onto another.

full pitch: Term used when the number of slots between the sides of an armature coil is equal to the number of slots of each pole.

fuller cell: Primary electric cell having two electrolytes: sulphuric acid and water, and a bichromate solution. These are separated by a porous cup. A cone-shaped zinc electrode is immersed in the cup, which also contains the sulphuric-acid solution and an ounce of mercury, and a carbon electrode is immersed in the bichromate solution.

fundamental units: Basic standards of measurement.

fuse: Safety device to prevent overloading a current. It consists of a short length of conducting metal which melts at a certain heat and thereby breaks the circuit.

fuse block: Insulated block designed to hold fuses.

fuse clip: Spring holder for a cartridge-type fuse.

fuse cutout: Fuse which, when melted, cuts out the circuit.

fuse link: An open fuse, or a length of fuse wire for refilling fuses.

fuse plug: Fuse mounted in a screw plug, which is screwed in the fuse block like a lamp in a socket.

fuse strip: A length of ribbon fuse as distinguished from wire fuse.

fuse wire: Wire made of an alloy which melts at a comparatively low temperature.

G: (a) Abbreviation for gram. (b) Symbol for mho, the unit of conductivity.

gage: Device for measuring.

galvanized: (a) Affected by galvanic action. (b) Metal coated with zinc.

galvanometer: Device for measuring small currents and voltages.

gang switch: Two or more switches installed in one box or one holder.

gas-filled: Filled with a gas as, for instance, an ordinary electric lamp.

gasoline-electric: Pertaining to a machine consisting of a gasoline engine, a generator driven by the engine, and one or more motors to produce electric power.

gauge: Same as "gage."

Gauss: Unit of flux density equal to one maxwell per square centimeter.

gauze brush: Generator or motor brush made of copper gauze.

Geissler tube: Gas-filled tubes, with or without fluorescent liquids, solids, or both, which emit light of various colors when a high-frequency current is passed through them.

gelatine battery: Battery having a jelly-like electrolyte.

generator: Machine that produces electricity.

generator busbar: Conductors on power switchboards to which a generator is connected.

generator loss: Difference between power required to drive a generator and the power it delivers, which is always less than the power input.

generator output: Power delivered by a generator, measured in watts or kilowatts.

geographical equator: Imaginary line around the earth halfway between the poles.

german silver: Alloy containing copper, nickel, and zinc, which is used for making resistance wire.

gilbert: Unit for measuring magnetic force. One gilbert is the magnetic force which sends one maxwell of flux through a magnetic circuit having a reluctance of one oersted.

glaze: Smooth finish applied to porcelain insulators to close the pores in order to prevent the absorption of moisture.

gramme armature: A ring type of armature.

graphite: A form of soft carbon.

gravity cell: Primary electric cell having two electrolytes, copper sulphate, and sulphuric-acid solutions, which are separated by gravity. The electrodes are zinc and copper.

gravity drop: A shutter or plate of an annunciator which, when released from a catch, drops by gravity.

Greenfield conductor: Flexible cable having a spirally wound metal covering.

Grenet cell: Primary electric cell of which the electrolyte is a solution of bichromate of potash in a mixture of sulphuric acid and water, and the electrodes are zinc and carbon. The zinc electrode is lifted out of the electrolyte when the cell is not in use.

grid: (a) Frame of a storage-battery plate having spaces in which the paste is pressed. (b) An element of a vacuum tube which controls the rate of electron emission from the filament to the grid.

grid condenser: Small fixed condenser inserted in the line connecting with the grid of a vacuum tube used as a detector.

grid leak: Resistance shunted across a grid condenser in a radio circuit to allow dissipation of an excessive charge on the grid.

ground: See "earth."

ground circuit: Part of an electric circuit in which the ground serves as a path for the current.

ground clamp: Clamp on a pipe or other metal conductor connected to the ground for attaching a conductor of an electrical circuit.

ground detector: Device used in a power station to indicate whether part of the circuit is accidentally grounded.

ground indicator: Same as "ground detector."

ground plate: Metal plate buried in moist earth to make a good ground contact for an electrical circuit.

ground return: Ground used as one conductor of an electrical circuit.

ground wire: Conductor connecting an electrical device or circuit to the ground.

grounded neutral wire: The neutral wire of a 3-way distribution system which is connected to the ground.

grounded primary: Primary circuit of an induction coil or transformer connected to the ground.

grounding brush: Brush for making a ground connection to a moving part.

Grove cell: Primary electric cell which is similar to a Bunsen cell but has a platinum electrode instead of a carbon electrode.

growler: Coil around an iron core which is placed in contact with the core of an armature. When an alternating current or a pulsating direct current is passed through the growler coil, it magnetizes the core, which in turn induces a current in the armature winding. The purpose is to show whether a short circuit exists in the armature coil.

gutta percha: Hardened sap of a tropical tree which has high insulating quality and great resistance to destructive agencies such as water.

guy: A wire, rope, chain, or similar support for a structure such as a telephone pole, radio mast, etc.

H

H.: An abbreviation or symbol for intensity of magnetism.

h.p.: Horsepower.

hand advance: A device for controlling the advance and retard of the sparks in the ignition system.

hand regulation: Controlling the current or voltage by means of a hand operated device.

hard drawn copper: A method of producing high-grade copper of good mechanical strength.

hard fiber: A material made from a number of sheets of paper compressed tightly together. A good insulator.

hard rubber: An electrical insulation made by vulcanizing rubber.

harmonic currents: A series of currents which have frequencies that are multiple of the main current.

heat coil: A small coil placed on a telephone circuit to protect it from stray currents.

heat loss: The energy lost in a conductor due to its resistance.

heat run: A test made on a generator or motor to determine the amount of heating that takes place.

heating unit: That part of a heating appliance through which the current passes and produces heat.

head guy: A cable or wire fastened near the top of a pole to hold it in place.

head light: A light placed on the front end of a moving vehicle.

helix: A coil of wire; a solenoid.

henry: The electrical unit of inductance.

Hertzian wave: A radio wave.

high frequency: An alternating current that has many thousand cycles or alternations per second.

high potential: A high pressure or voltage, usually about six hundred volts.

high tension: A term used to refer to high voltage.

high tension magneto: A magneto used for ignition work in which the high-voltage current is produced in the magneto generator without the use of a separate induction coil.

holding magnet: An electromagnet used to hold metal objects while work is being done on them.

Holtz machine: A static electricity machine.

holophane: An electrical lighting globe with special surface for diffusing light.

homopolor generator: A generator having poles of one magnetic polarity only, instead of having alternate north and south pole.

hook-switch: A switch and hook on a telephone which is operated by placing or removing the receiver from that hook.

horizontal candle-power: The amount of light given off by a lamp measured in a horizontal direction from the light.

horn gap: A gap which is narrow at the bottom and widens out towards the top.

horsepower: The unit of power or work. An electrical horsepower is equal to 746 watts.

horsepower hour: The amount of power performed by 746 watts per one hour.

horseshoe magnet: A magnet bent in the shape of the letter U, or horseshoe.

hot conductor: A term used to refer to a conductor or wire which is carrying a current or voltage.

hot-wire meter: A meter which obtains a reading by the expansion of the length of wire or metal through which current flows.

howler: A device used in a telephone exchange to cause a noise in the receiver to indicate to the customer that the receiver has been left off the hook.

humming: A noise caused by the rapid magnetizing and demagnetizing of the iron core of a transformer, motor, or generator.

hunting: A condition in an electrical circuit where one machine tends to oscillate or run faster than another, and then run slower.

hydraulic: Pertaining to water or fluids in motion.

hydroelectric: The production of electricity by water-power.

hydrometer: An instrument or device which shows the specific gravity of a liquid as compared to water.

hysteresis: The tendency of magnetism to lag behind the current that produces it.

hysteresis curve: A curve that shows the relation between the magnetizing current and the amount of magnetism produced by it.

hysteresis loss: The heat produced by repeatedly magnetizing and demagnetizing the iron core of a machine.

I: An abbreviation for amperes of current.

I.E.S.: Illuminating Engineering Society.

i.h.p.: Indicated horsepower.

I-beam: A steel beam made in the form of a capital I.

idle coil: A coil which does not produce any voltage or through which no current flows.

ignition: The igniting of a combustible charge in the cylinder of a gas engine.

ignition battery: A battery used to furnish the ignition current for an automobile engine.

ignition coil: An induction coil that produces a high-voltage current which jumps the gap in a spark-plug and ignites the charge in an automobile engine.

ignition distributor: A device that connects the proper spark-plug to the high-tension current at the right time in an automobile engine.

ignition generator: A generator used to produce the ignition current for an automobile engine.

ignition spark: The spark that passes between the gaps of the spark-plug, inside an automobile cylinder.

ignition switch: A switch that is used for turning on and off the primary ignition coil.

ignition timer: A device that closes and opens the primary circuit of an induction coil at the proper instant, to produce a spark in a cylinder of an automobile engine.

illumination: The directing of light from its source to where it can be used to the best advantage.

impedance: The apparent resistance of a circuit to alternating current. It is composed of resistance and reactance.

impedance coil: A reactance or choke coil, used to limit the flow of current.

impregnated cloth: A cotton cloth that has been saturated with insulating varnish and dried.

impressed voltage: The voltage or pressure acting upon any device.

impulse: A sudden change, such as an increase or decrease in voltage or current.

incandescent lamp: A lamp in which light is produced by the heating of a small filament inside of a glass bulb

inclined coil instrument: A voltmeter or ammeter in which the coil or moving vane are inclined in relation to the pointer.

incomplete circuit: An open circuit.

India rubber: A soft rubber used to insulate or cover electrical conductors and wires.

indicated horsepower: The horsepower determined by calculation taken from an indicator diagram.

indicating switch: A switch that shows whether it is turned "ON" or "OFF."

indirect lighting: Light that is thrown against a ceiling having a light colored surface and reflected and diffused in the room being lighted.

induced current: Current that is produced by inductance from another circuit.

induced e.m.f.: A voltage that is produced by induction from another circuit.

induced magnetism: Magnetism that is produced by electric current or by the action of other magnetism.

induced voltage: A voltage or pressure produced by induction.

inductance: The ability of an electric circuit to produce induction within itself.

inductance coil: A coil connected in an electric circuit in order to increase the resistance of that circuit to alternating current.

induction: The influence exerted by a magnet or magnetic field upon conductors.

induction coil: A coil used to produce a high-voltage. It consists of two windings placed on an iron core. The voltage is produced by stopping quickly the flow of current in the coil.

induction furnace: An electric furnace in which the metal forms a secondary circuit of the transformer and is heated by current flowing through the metal.

induction generator: An induction motor, operated about synchronous speed, which produces an electric current.

induction meter: A meter used on alternating current in which rotation of a disk is caused by the magnetic lines of force produced by a current and a voltage coil passing through the disk.

induction motor: An alternating-current motor which is operated by induced magnetism from the winding placed on the stator. It does not operate at synchronous speed.

induction regulator: A transformer in which the voltage produced in a secondary winding is varied by the changing of position of the primary winding.

inductive load: The load connected to an alternating-current system which causes the current to lag behind the voltage.

inductive reactance: The reactance produced by self-inductance.

inductive resistance: The apparent resistance that is caused by self-induction in a circuit.

inductor: That part of an armature winding which lies entirely on one side of the armature coil, and in which a voltage is produced.

industrial controller: A device or rheostat for controlling the speed of electric motors.

inertia: The tendency of a body to remain at rest or in motion at the same speed.

initial voltage: The pressure at the start; as the voltage at the terminal of a storage battery when it is placed on change; that voltage which causes the appearance of corona around an electric conductor.

input: All of the power delivered to an electric device or motor.

inside wiring: The wiring inside of a residence or building.

installation: All of the electrical equipment or apparatus used in a building including the wiring.

instrument transformer: A transformer used to change the voltage or current supplied to meters.

insulate: To place insulation around conductors or conducting parts of a device or object.

insulating: The placing of insulation around electrical conductors.

insulating compound: An insulating wax which is melted and poured around electrical conductors in order to insulate them from other objects.

insulating joint: A thread or coupling in which the two parts are insulated from each other.

insulation resistance: The resistance offered by an insulating material to the flow of electric current through it.

insulating varnish: A special prepared varnish which has good insulating property and is used to cover the coils and windings on electric machines and improve the insulation.

insulator: A device used to insulate electric conductors.

intake: A place where air or water enters a machine, tunnel, or pipe.

integrating meter: A meter that keeps the record of the total amount of power, current, etc., that passes through it in a given time.

intensity: The intensity of the current is the number of amperes that flows through a conductor in a given time.

intercommunicating telephone: A telephone system that connects up to the several offices in the sam building or plant without the use of a central operator.

interior wiring: Wiring placed on the inside of buildings.

intermittent current: A current, that starts and stops its flow at regular intervals.

intermittent rating: When a machine is operated for a short time only and allows a long period of rest, it has an intermittent rating.

internal circuit: The circuit formed inside a device or machine.

internal resistance: The resistance of the winding of an electrical machine, or between terminals of a primary cell or a storage battery.

internal short-circuit: A short-circuit occurring between the positive and negative plates in a storage battery due to a defective separator.

internal wiring: The wiring inside of a device or a machine.

interpoles: Magnetic poles placed between the main poles of a motor or generator.

interrupter: A device that opens or closes a circuit many times per second.

interrupter contact: The contact where a circuit is broken by an interrupter.

interrupter gap: The greatest amount of distance or space between the contacts of an interrupter.

invar: A resistance wire composed of nickel and steel.

inverse ratio: A ratio where one value increases and the other value decreases.

inverted converter: A rotary or synchronous converter which changes direct current into alternating current.

ion: The two minute parts into which a molecule is divided when it is separated into its elements.

I^2R loss: The power loss due to the current flowing through the conductor which has resistance. This loss is converted into heat.

iron loss: The hysteresis and eddy current losses in iron cores of electric machinery.

ironclad armature: An armature in which the windings are placed in slots cut in the armature core.

ironclad magnet: A magnet which has an iron core extending around the outside of the coil and through which the magnetism flows.

isolated plant: An electric light plant used to furnish power for a small community or a few firms, and the power of the plant is not sold to the public.

J: Abbreviation for joule.

jack: The terminal of two telephone lines on a switchboard of a telephone exchange.

joint: The uniting of two conductors by means of solder.

joint resistance: The combined or total resistance of two or more resistances connected in series or parallel.

joule: A unit of electrical work. A current of one ampere flowing through a resistance of one ohm for one second.

journal: That part of a shaft that turns or revolves in the bearings.

jump spark: A spark that passes between two terminals or across a gap. It is produced by high voltage.

jumper: A temporary connection made around part of a circuit.

junction box: A box in a street distribution system where one main is connected to another main; also a box where a circuit is connected to a main.

K

K.: Abbreviation or symbol for dielectric constant.

k.w.: Abbreviation for kilowatt.

kaolin: A kind of clay used in making porcelain insulators.

keeper of magnet: A bar of soft-iron placed across the poles of a magnet when it is not being used.

Key: A device for opening and closing a circuit by moving a lever. It is used in telephone and telegraph apparatus.

key switch: A switch for turning on and off electric circuits which are operated by means of a special key.

key socket: A socket with a device that opens and closes the circuit, thus turning the lamp off or on.

keyless socket: A socket which does not have a key or device for turning on or off the lamp.

kicking coil: A reactance or choke coil.

kilo: A prefix when placed before a word means 1000 times that indicated by the word.

kiloampere: One thousand amperes.

kilovolt: One thousand volts.

kilowatt: One thousand watts.

kilowatt-hour: One thousand watt-hours.

knife switch: A switch that has a thin blade that makes contact between two flat surfaces or short blades to complete the circuit.

knob insulator: A porcelain knob to which electric wires may be fastened.

L

L.: An abbreviation for length.

lag: To drop behind.

lag of brushes: The distance the brushes are shifted on a motor or generator in order to prevent sparking.

lagging coil: A small coil used in alternating watt-hour meter to compensate for the lagging current in the voltage coil.

lagging current: The lagging of the current behind the voltage wave in an inductive alternating-current system.

laminated: Built up out of thin sheets or plates which are fastened together.

laminated core: A core built up of thin soft iron sheets placed side by side and fastened together.

laminations: One of the plates used in building a laminated core.

lamp: A device used to produce light.

lamp bank: A number of incandescent lamps connected in series or in parallel and used as resistances.

lamp base: The metal part of an incandescent lamp which makes contact with the socket.

lamp bulb: A term used in referring to an incandescent electric lamp.

lamp circuit: A branch circuit supplying current to lamps only, and not to motors.

lamp cord: Two flexible stranded insulated wires twisted together and used to carry the current from the outlet box to the lamp socket.

lamp dimmer: An adjustable resistance connected in a lamp circuit in order to reduce the voltage and the brightness of the lamps.

lamp socket: A receptacle into which the base of the lamp is inserted, and which makes connection from the lamp to the circuit.

lap winding: An armature winding in which the leads from the coil to the commutator lap over each other.

lap-wound armature: An armature that has a lap winding.

lateral: A conduit that branches off to the side from the main conduit.

lava: A kind of stone that has insulating properties.

lead (pronounced lĕd): An acid resisting metal that is used in making parts for storage batteries.

lead battery: A storage battery in which the plates are made from lead.

lead burning: The process of uniting two pieces of lead together by melting the edges.

leads (pronounced leeds): Short lengths of insulated wires that conduct current to and from a device.

lead of brushes: The distance that the brushes are moved on the commutator of a generator or motor to prevent sparking.

leading current: When the current of an alternating-current system reaches its maximum value before the voltage does, it is called a leading current.

leading-in wires: Wires used to carry current from the outside of buildings to the inside of buildings.

leak: A loss of charge in a storage battery where current can flow through a circuit, or to ground, due to defective insulation.

leakage flux: Lines of force or magnetism that do not flow through the path intended for them but take another path and do not do any useful work.

Leclanche cell: A primary cell which uses carbon and zinc rods or plates for electrodes.

left-hand rotation: A shaft or motor that revolves in a counter clockwise direction; that is, opposite to that of the hands of a clock.

Leyden jar: A glass jar covered inside and out with a thin metal covering, and used as a condenser.

lifting magnet: An electromagnet used to lift iron and steel objects.

light load: A load that is less than the usual or normal load on the circuit.

lighting fixture: An ornamental device that is fastened to the outlet box in the ceiling and which has sockets for holding the lamps.

lighting transformer: A transformer that is used to supply a distribution circuit that does not have motors connected to it.

lightning arrester: A device that allows the lightning to pass to the ground, thus protecting electrical machines.

lightning rod: A rod that is run from the ground up above the highest point of a building.

limit switch: A switch that opens the circuit when a device has reached the end of its travel.

line of force: An imaginary line which represents the direction of magnetism around a conductor or from the end of a magnet.

line drop: The loss in voltage in the conductors of a circuit due to their resistance.

line insulator: An insulator for use on an overhead transmission line.

line reactance: The reactance in the transmission line or conductor outside of the supply station.

line resistance: The resistance of the conductor forming the transmission line.

lineman: A man who erects or works on an electric transmission line.

link fuse: A fuse that is not protected by an outside covering.

litharge: A compound made from lead used in the active material of storage battery plates.

live: A circuit carrying a current or having a voltage on it.

load: The work required to be done by a machine. The current flowing through a circuit.

load control: Changing the output of a generator as the changes of load occur on a circuit.

load dispatcher: A person who supervises or controls the amount of load carried by the generating station on a system.

load factor: The average power consumed divided by the maximum power in a given time.

loading coils: Small coils placed in series with telephone lines in order to improve the transmission of speech.

local action: A discharge between different parts of a plate in a storage battery or primary cell caused by impurities in the parts used.

local current: An Eddy current.

locked torque: The twisting or turning power exerted by a motor when the rotating part is held stationary and normal current supplied to the winding.

lodestone: Magnetic iron ore.

log: A record of events taken down as they occur.

long shunt: Connecting the shunt across the series field and armature, instead of across the armature terminals.

loop circuit: A parallel or multiple circuit.

loop test: A test using the Wheatstone bridge, and a good line to locate an accidental ground on a line.

loose contact: A poor connection that does not make proper contact.

loud speaker: An electrical device that reproduces sound loud enough to be heard across a room.

low frequency: A current having a small number of cycles per second.

low potential: A system where the voltage between wires is usually less than 600 volts.

low tension: Low pressure or voltage.

low tension winding: The winding on a transformer which produces or has the lowest voltage.

low voltage release: A device that opens the circuit when the voltage drops down to a certain value, for which it is adjusted.

lugs: Terminals placed on the end of conductors to enable the wire to be attached or detached quickly.

lumen: The unit of electric lighting.

luminarre: An ornamental electric lighting fixture.

luminosity: In electric lighting work it is the brightness of a color compared with light.

luminous flux: In lighting work it is the amount of light directed down toward the point where it can be used.

M

M: A symbol of mutual induction the unit for which is a henry.

M.C.B.: Master Car Builder.

M.D.F.: Main distributing frame in a telephone exchange.

m.f.d.: Microfarad.

M-G: An abbreviation for motor-generator sets.

m.p.h.: Miles per hour.

machine rating: The amount of load or power a machine can deliver without overheating.

machine switching: A telephone exchange where the connections from one party to another are made by a machine instead of by an operator.

magnet: A body that will attract iron or steel.

magnet charger: A large electromagnet used to magnetize permanent magnets.

magnetic coil: The winding of an electromagnet.

magnet core: The iron in the center of the electromagnet.

magnet winding: The wire wound on a spool, forming an electromagnet.

magnet wire: A small single conductor copper wire insulated with enamel, cotton, or silk, used in winding armatures, field coils, induction coils, and electromagnets.

magnetic attraction: The pull or force exerted between two magnets or between magnets and an iron or steel body.

magnetic blow-out: A magnet arranged so that the arc between contacts is quickly lengthened and extinguished.

magnetic brake: A friction brake which is applied or operated by an electromagnet.

magnetic bridge: An instrument that measures the permeability and reluctance of magnetic material.

magnetic circuit: The paths taken by lines of force in going from one end of the magnet to the other.

magnetic compass: A small magnetized needle which indicates north and south directions.

magnetic contactor: A device, operated by an electromagnet, which opens and closes a circuit.

magnetic density: The amount of magnetism or magnetic lines of force per square inch or centimeter.

magnetic dip: The angles that a balanced needle makes with the earth when it is magnetized.

magnetic equator: An imaginary line joining the points about the earth where the compass needle does not have any dip.

magnetic field: The magnetic lines of force that pass in the space around a magnet.

magnetic flux: Magnetism or the number of lines of force in a magnetic circuit.

magnetic force: The attraction between magnetic poles or magnets, producing magnetism in a magnetic body by bringing it near a magnetic field.

magnetic lag: The tendency for magnetism to lag behind the current or force producing magnetism.

magnetic leakage: Lines of force that do not do useful work by passing through a path that is not in a working field.

magnetic lines of force: Magnetism about a conductor or flowing from magnet.

magnetic material: Materials which conduct lines of force easily—iron and steel.

magnetic needle: A small magnet that points in the direction of the magnetic lines of force about the earth.

magnetic pole: The ends of the magnet where the magnetism enters or leaves the magnet.

magnetic potential: Magnetic pressure which produces a flow of magnetic lines of force.

magnetic pulley: A pulley with an electromagnet inside of it, and used to separate iron and steel from other materials passed over it.

magnetic saturation: The greatest number of magnetic lines of force or magnetism that a body or substance can carry.

magnetic screen: A soft iron body around which magnetism is conducted instead of going through the center of that object.

magnetic shunt: A definite path for magnetic lines of force to pass through instead of the main path.

magnetic switch: A switch that is operated or controlled by an electromagnet.

magnetism: That invisible force that causes a magnet to attract iron and steel bodies.

magnetite: Magnetic iron ore.

magnetization curve: A curve that shows the amount of magnetism, expressed in lines of force, produced by a certain magnetizing force.

magnetize: To cause a substance to become a magnet.

magnetizing force: That force which produces magnetism. It is measured in ampere-turns.

magneto: A small generator that has a permanent field magnet.

magneto ignition: Igniting the charge in a combustion engine from a magneto generator.

magnetomotive force: That force which produces magnetism; it is expressed in ampere-turns.

main: The circuit from which all other smaller circuits are taken.

main feeder: A feeder supplying power from the generating station to the main.

make-and-break ignition: Igniting the charge in an internal combustion engine by the spark produced when contacts carrying current are opened.

maintenance: Repairing and keeping in working order.

manhole in conduit: An opening or chamber placed in a conduit run large enough to admit a man to splice or join cables together.

manganese steel: An alloy of steel having a large percent of the metal called manganese.

manual: Operated by hand.

mariner's compass: A compass used by sailors for directing the course of a ship.

master switch: A switch that controls the operation of other switches or contact switches.

maximum demand: The greatest load on a system occurring during a certain interval of time.

maximum demand meter: A meter that registers or indicates the greatest amount of current or power passing through a circuit within a given time.

maxwell: A unit of magnetic flux or lines of force.

mazda lamp: A certain trade name for an incandescent lamp using a tungsten filament.

mean horizontal candle-power: The average candle-power measured on a horizontal plane in all directions from the lamp filament.

mean spherical candle-power: The average candle-power of a lamp measured in all directions from the center of the lamp.

meg or mega: A prefix that means one million times.

megger: An instrument that measures the resistance in megohms.

meghoms: A resistance of one million ohms.

mercury: A silvery white metal liquid; often called quicksilver.

mercury-arc rectifier: A rectifier in which alternating current is changed to direct current by the action of mercury vapor on electrodes.

mercury vapor lamps: The lamps or lights in which light is produced by passing a current through mercury vapor.

mesh connection: A closed circuit connection in armature winding.

messenger wire: A wire used to support a trolley, feeders, or cable.

metal conduit: Iron or steel pipe in which electric wires and cables are installed.

metal moulding: A metal tube or pipe, installed on the ceiling or walls of a building, in which electric wires are installed.

metallic circuit: A circuit that uses wires to return the current to the starting point instead of returning it through the ground.

metallic filament: An incandescent lamp filament made from a metal such as tantalum or tungsten.

meter: A device that records and indicates a certain value of electricity.

meter loops: Short pieces of insulated wire used to connect a watthour meter to the circuit.

metric system: A system of weights and measures based upon a meter (39.37 inches) for length and a gram ($\frac{1}{28}$ ounce) for weight

Mho: The reciprocal of the resistance of a circuit which is called conductivity.

mica: A transparent mineral substance used for insulating commutators.

mica undercutter: A tool used to cut the mica below the surface of the commutator segment.

micanite: A trade name for small pieces of flake mica cemented together with an insulating compound.

micro: A prefix meaning one-millionth part.

micro-ampere: The one-millionth part of an ampere. $\frac{1}{1,000,000}$ or .000001 amperes.

microfarad: One-millionth of a farad.

microhm: One-millionth of an ohm.

microphone: A telephone transmitter in which the resistance is varied by a slight change in pressure on it.

microvolt: One-millionth of a volt.

mil: One-thousandth part of an inch; $\frac{1}{1000}$ or .001 inch.

mile-ohm: A conductor that is one mile long and has a resistance of one ohm.

mil-foot: A wire that is one-thousandth of an inch in diameter and one foot long.

milli: Prefix to a unit of measurement, denoting one-thousandth part of it.

milli-ammeter: An instrument that reads the current in thousandths of an ampere.

milli-ampere: $\frac{1}{1000}$ or .001 amperes. One-thousandth of an ampere.

milli-henry: One-thousandth of a henry.

milli-volt: One thousandth of a volt.

milli-voltmeter: A voltmeter that reads the pressure in one-thousandth of a volt.

mineralac: A trade name of an insulating compound or wax.

miniature lamp: The smallest size of incandescent lamp that uses a screw threaded base.

mirror galvanometer: A very sensitive galvanometer with a mirror attached to the moving element which reflects a spot of light over a scale.

moment: That which produces motion.

monel metal: An alloy of nickel and copper that is not eaten away by acids.

momentum: The tendency of a body to remain at rest or in motion at the same speed.

molecule: The smallest existing particle of a compound substance.

moonlight schedule: A list showing the time to turn the street lights out one hour after the moon rises, and turn them on one hour before the moon sets.

Morse code: A series of dots and dashes as signals transmitted by telegraph used to transmit messages.

motor: A machine that changes electrical energy into mechanical power.

motor converter: A form of rotary or cascade converter.

motor circuit: A circuit supplying current to an electric motor.

motor-generator: An electric motor driving a generator changing alternating to direct current or the reverse.

moulded insulation: A form of insulating material that can be placed in a mold and pressed into shape.

moulding: A wooden or metal strip provided with grooves to receive rubber covered electric wires.

moving coil meter: An electrical instrument of the d'Arsonval type which has a coil of fine wire moving between permanent magnets.

multiple: Connected in parallel with other circuits.

multiple circuit: A circuit in which the devices are connected in parallel with each other.

multiple series: A parallel connection of two or more series circuits.

multiple winding: A winding where there are several circuits in parallel.

multiple unit control: Controlling the operation of motors on several cars of an electric train from one point.

multiplex telegraphy: Sending one or more messages in both directions in the same circuit at the same time.

multiplex wave winding: A wave-wound armature that has more than two circuits in parallel.

multiplier: An accurately calibrated resistance connected in series with a voltmeter to enable it to be used on higher voltage circuits

multipolar: Having more than two pole-pieces and field coils.

multi-speed: An electric motor that can be operated at several definite speeds.

mush coil: An armature coil that is not wound in regular layers.

N

N: A symbol used for revolutions per second or minute; often used to denote the North pole of a magnet.

N.E.C.: Abbreviation for National Electric Code; often called Underwriter's Code.

N.E.L.A.: Abbreviation for National Electric Light Association.

N.F.P.A.: Abbreviation for National Fire Prevention Association.

n.h.p.: Abbreviation for nominal horsepower.

name plate: A small plate placed on electrical machines which gives the rating of the machine and the manufacturer's name.

natural magnet: Magnetic ore or lodestone.

needle: A magnetized piece of steel which can be swung from the center and will point in the direction in which the magnetic lines of force are flowing.

needle point: The sharp point on a spark gap.

negative: The point towards which current flows in an external electrical circuit; opposite to positive.

negative brush: The brush of a generator out of which current enters the armature. In a motor the brush at which current leaves the armature.

negative charge: Having a charge of negative electricity.

negative conductor: The conductor that returns the current to the source after it has passed through a device and has been used.

negative electrode: The electrode by which the current leaves an electrolyte and returns to its source.

negative feeder: A feeder connected to the negative terminal on a generator to aid the current returning to the generator.

negative plate: The sponge lead plate of a lead acid-battery. In a primary cell the terminals to which the current returns from the external circuit.

negative pole: The S-pole of a magnet. The pole that the lines of force enter the magnet.

negative side: That part of the circuit from where the current leaves the consuming device to where it re-enters the generator.

negative terminal: That terminal to which the current returns from the external circuit.

neon: An inert gas used in electric lamps.

nernst lamp: A lamp in which light is produced by passing the current or electricity through rare oxide contained in a tube.

network: A number of electrical circuits or distribution lines joined together.

neutral: Not positive or negative although it may act as positive to one circuit and negative to another.

neutral conductor: A middle conductor of a three-wire direct-current or single-phase circuit.

neutral induction: The variation of current in one circuit which causes a voltage to be produced in another circuit.

neutral position: That point on the commutator where the armature conductors do not produce any voltage, because they are not cutting lines of force at that point.

neutral terminal: A terminal which may be positive to one circuit and negative to another circuit.

neutral wire: That wire in a three-wire distribution circuit which is positive to one circuit and negative to the other.

nichrome: An alloy of nickel and chromium which forms a resistance wire that can be used at a high temperature.

nickel: A silver white metal.

nickel silver: An alloy of copper, zinc, and nickel.

nickel steel: An alloy steel containing a sma.l per cent of nickel.

nitrogen lamp: An incandescent lamp containing nitrogen or other inert gas instead of a vacuum.

non-conductor: That material which does not easily conduct electric current; an insulator.

non-inductive: Having very little self-induction.

non-inductive load: A load connected to a circuit that does not have self-induction. With alternating-current circuit, the current is in phase with the voltage.

non-inductive winding: A winding arranged so that it does not have any self-induction.

non-magnetic: Materials that are not attracted by a magnet are called non-magnetic.

normal: The general or usual conditions for that particular device or machine.

North pole: The end of the magnet at which the lines of force leave it. The end of a freely suspended magnet that will point towards the North.

numerator: In fractions the word or number written above the horizontal line.

O

O.K.: An abbreviation which means all right.

oersted: The unit of magnetic reluctance which is the resistance of metal to the flow of magnetism through them.

ohm: The unit used to express the resistance of a conductor to the flow of electric current through it.

Ohm's law: A rule that gives the relation between current, voltage, and resistance of an electric circuit. The voltage (E) is equal to the current (I) in amperes times resistance (R) in ohms. The current (I) equals the voltage (E) divided by the resistance (R) of the circuit. The resistance (R) is equal to the voltage (E) divided by the current (I).

ohm-mile: A conductor a mile long and has a resistance of one ohm.

ohmic resistance: The resistance of a conductor due to its size, length, and material.

oil circuit breaker: A device that opens an alternating-current circuit in a tank of oil which extinguishes the arc.

oil switch: A switch whose contacts are opened in a tank of oil.

oiled paper: A paper treated with an insulating oil or varnish.

open circuit: A break in a circuit. Not having a complete path or circuit.

open circuit battery: A primary cell that can only be used for a short time, and requires a period of rest in order to overcome polarization.

open coil armature: An armature winding in which the ends of each coil are connected to separate commutator bars.

open delta connection: A transformer connection in which two single-phase transformers are used to form two sides of a delta connection.

open wiring: Electric wires fastened to surfaces by the use of porcelain knobs. Wiring that is not concealed.

ordinate: The vertical lines drawn at various points along the horizontal base line to indicate values on that base line.

oscillating discharge: A number of discharges obtained one after another from a condenser; each one is less than the one before.

oscillograph: A very sensitive and rapid galvanometer which shows changes occurring in electrical circuits.

outboard bearing: A bearing placed on the outside of a pulley of a machine.

outlet: A place where electrical wires are exposed so that one can be joined to the other.

outlet box: An iron box placed at the end of conduit where electric wires are joined to one another and to the fixtures.

output: The amount of current in amperes or watts produced by a generator or a battery.

overcompound: When the series field coils of a generator are designed so that the voltage will increase with an increase in load, the generator is said to be overcompounded.

overdischarge: Discharge from a storage battery after the voltage has dropped to the lowest normal discharge value.

overhead: Electric light wires carried out doors on poles.

overload: Carrying a greater load than the machine or device is designed to carry.

overload capacity: The amount of load beyond a rated load that a machine will carry for a short time without dangerously overheating.

overvoltage: A voltage higher than the normal or usual voltage.

ozone: A form of oxygen produced by electrical discharge through air.

P: Abbreviation for power.

P.B.X.: Private branch telephone exchange.

P.D.: Potential difference.

panel box: The box in which switches and fuses for branch circuits are located.

parabolic reflector: A reflector built in the form of a parabolic curve in order to reflect the light in a narrow beam.

paraffin: A wax used for insulating bell wire.

parallax: The difference caused by reading the scale and pointer of an instrument at an angle instead of straight in front of it.

parallel: Two lines extending in the same direction which are equally distant at all points. Connecting machines or devices so that the current flows through each one separately from one line wire to another line wire. Also called multiple.

parallel circuit: A multiple circuit. A connection where the current divides and part flows through each device connected to it.

parallel series: A multiple series. A number of devices connected in series with each other, forming a group; and the groups are connected in parallel with each other.

parallel winding: A lap armature winding.

paramagnetic: Material that can be attracted by a magnet.

para rubber: The best grade of india rubber.

pasted plate: A storage battery plate in which the active material is prepared as a paste and forced into openings in the grid.

peak load: The highest load on a system, or generator, occurring during a particular period of time.

peak voltage: The highest voltage occurring in a circuit during a certain time.

pendant switch: A small push button switch, hanging from the ceiling by a drop cord, used to control the flow of current to a ceiling light.

permanent magnet: A magnet that holds its magnetism for a long time.

permeability: The ease with which a substance conducts or carries magnetic lines of force.

permeability curve: A curve that shows the relation of the magnetizing force (ampere-turns) and number of lines of force produced through a certain material.

permeameter: An instrument used to test the permeability of iron and steel.

permittivity: The dielectric constant.

peroxide of lead: A lead compound used in making storage battery plates.

petticoat insulator: An insulator the bottom part of which is in the shape of a cone with the inside hollow for some distance.

phantom line: An artificial line over which messages can be sent the same as over an ordinary line.

phase: The fraction of a period of cycle that has passed since an alternating voltage or current has passed through zero value in the positive direction.

phase advancer: A machine used to improve the power factor of a system by overcoming the logging current.

phase angle: The difference in time between two alternating-current waves expressed in degrees. A complete cycle of 360 degrees.

phase converter: A machine that changes the number of phases in an alternating-current circuit without changing the frequency.

phase failure: The blowing of a fuse or an opening of one wire or line in a two- or three-phase circuit.

phase indicator: A device that shows whether two electric machines are "in step" or in synchronism.

phase rotation: The order in which the voltage waves of a three-phase circuit reach their maximum value, as ABC or ACB.

phase shifters: Devices by which power-factor can be varied on a circuit when testing meters.

phase splitter: A device that causes an alternating current to be divided into a number of currents that differ in phase from the original.

phase winding: One of the individual armature windings on a polyphase motor or generator.

phosphor bronze: Bronze to which phosphor has been added in order to increase its strength.

photometer: An instrument used to measure the intensity of light.

pig tail: Five braided copper wires used to connect the carbon brush to its holder.

pike pole: A small pole with a sharp spike in one end. It is used by wiremen in raising and setting wood poles.

pilot brush: A small brush used to measure the voltage between adjacent commutator bars.

pilot cell: A cell in a storage battery used as a standard in taking voltage and specific gravity readings.

pilot lamp: A small lamp used on switchboards to indicate when a circuit switch or device has operated.

pitch: The number of slots between the sides of an armature coil. The distance from a certain point on one to a like point on the next.

pith balls: Small balls made from the light soft spongy substance in the center part of some plants and corn cobs.

pivots of meters: The shaft to which the moving part of the meter is fastened and which turns on a bearing.

Planté plates: A storage battery plate in which the active material is formed by charging and discharging the battery many times

plate condenser: A condenser formed by a number of plates with insulating material between them.

plating dynamo: A generator that produces a low voltage direct current for use in electroplating work.

platinum: A gray-white metal that is not easily oxidized and which makes good contact points.

platinum-iridium: An alloy of platinum and iridium, which is a harder metal than platinum.

plug: A screw thread device that screws into an electric light socket and completes the connection from the socket to the wires fastened to the plug.

pocket meter: A small voltmeter or ammeter mounted in a case that can be carried in the coat pocket.

polar relay: A relay that operates when the direction of the flow of current changes.

polarity: Being positive or negative in voltage, current flow, or magnetism.

polarity indicator: An instrument that indicates the positive or negative wires of a circuit.

polarity wiring: Using a white or marked wire for the ground side of a branch circuit.

polarization: The forming of gas bubbles on the plates of a primary cell which reduces the current produced by the cell.

polarized: Having a definite magnetic polarity.

polarized armature: The armature of a magnet that has a polarity of its own and which is attracted only when the direction of the flow of current in the windings produces a pole of opposite polarity.

pole: The positive and negative terminal of an electric circuit. The ends of a magnet.

pole changer: A device that changes direct current into alternating current.

pole piece: The end of the field magnet or electromagnet that forms a magnetic pole.

pole pitch: The number of armature slots divided by the number of poles.

pole shoe: A piece of metal having the same curve as the armature that is fastened to the field magnet of a generator or motor.

pole strength: The number of magnetic lines of force produced by a magnet.

pole tips: The edges of the field magnets toward and away from which the armature rotates.

polyphase: Having more than one phase.

polyphase circuit: A two- or three-phase circuit.

polyphase transformer: A transformer in which the windings of all the phases are located inside the same case or cover.

porcelain: A hard insulating material made from sand and clay which is molded into shape and baked.

porous cell: A porous jar used with primary cells that use two different electrolytes that must be kept separate.

portable instrument: A meter so designed that it can be moved from one place to another.

positive: The point in a circuit from which the current flows; opposite to negative.

positive brush: The brush of a generator from which the current leaves the commutator; the brush of the motor through which current passes to the commutator.

positive electricity: The kind of electricity produced by rubbing a glass rod with silk.

positive electrode: The electrode or terminal that carries the current into the electrolyte.

positive feeder: A wire or cable acting as a feeder that is connected to the positive terminal of a generator.

positive plate: The peroxide of lead plate in a lead-acid storage battery.

positive terminal: The terminal of a battery or generator from which the current flows to the external circuit.

potential: The pressure, voltage, or electromotive force that forces the current through a circuit.

potential coil: The voltage or pressure coil of a meter that is connected across the circuit and is affected by changes in voltage.

potential regulator: A device for controlling or regulating the voltage of a generator or circuit.

potential transformer: A transformer used to step the voltage down for voltmeters and other instruments.

potentiometer: An instrument used to compare a known or standard voltage with another voltage.

pothead: A flared out pot or bell attached to the end of a lead covered cable and filled with insulating compound.

poundal: The unit of force which, acting for one second, will give a body that has mass of one pound a velocity of one foot per second

power: The rate of doing work. In direct current circuits it is equal to $E \times I$. The electrical unit is the watt.

power circuit: Wires that carry current to electric motors and other devices using electric current.

power factor: The ratio of the true power (watts) to the apparent power (volts $\times$ amperes). Cosine of the angle of lag between the alternating current and voltage waves.

power factor meter: A meter that indicates the power factor of the circuit to which it is connected.

power loss: The energy lost in a circuit due to the resistance of the conductors; often called I^2R loss.

power plant: The generators, machines, and buildings where electrical power or energy is produced.

practical units: The electrical units used in everyday practical work —the ohm, volt, ampere, watt, etc.

precision instrument or meter: A very accurate meter or instrument used in testing or comparing other meters.

press board: A hard smooth paper or cardboard used for insulation in generators and transformers.

pressure: The voltage which forces a current through a circuit; also called potential difference.

pressure wires: Wires going from the end of a feeder to a voltmeter in the power station.

primary: That which is attached to a source of power, as distinguished from the secondary

primary cell: A cell producing electricity by chemical action, usually in acid acting on two different metallic plates.

primary circuit: The coil or circuit to which electric power is given and which transfers it to the secondary by induction.

primary winding: The winding which receives power from the outside circuit.

prime mover: An engine, turbine, or water wheel that drives or operates an electric generator.

prony brake: A friction brake or a pulley used as a dynamometer to measure the torque turning power of a shaft.

proportional: A change in one thing which causes a relative change in another thing.

protective reactor: A reactance coil used in a circuit to keep the current within a safe value when a short circuit occurs.

pull boxes: An iron box placed in a long conduit, or where a number of conduits make a sharp bend.

pull-offs: A hanger used to keep the trolley wire in proper place on a curve.

pulsating current: A current that flows in the same direction all the time, but rises and falls at regular intervals.

puncture: The breaking through insulation by a high voltage.

push button: A small contact device having a button which, when pressed, closes a circuit and causes a signal bell to ring.

push-button switch: A switch that opens and closes a circuit when a button is pushed.

push - pull transformer: A transformer used in radio work with a tap brought out at the center of the coil windings.

pyrometer: An instrument that indicates or measures temperatures higher than a thermometer will handle.

Q: Abbreviation for "quantity" of electricity. The unit is coulomb or ampere-hours.

Q.S.T.: A radio code call—"Have you received the general call"?

quad: An abbreviation for quadruple telegraph; means Four.

quaded cable: A telephone or telegraph cable in which every two pairs (4 wires) are twisted together.

quadrature: Angle of 90 electrical degrees or quarter cycle difference between two alternating-current waves.

quarter phase: Same as two phase. The voltage waves are one-fourth of a cycle apart.

quick-break switch: A knife switch arranged so it will break the circuit quicker than when pulled open by hand.

R

R: Abbreviation for resistance, the unit of which is the ohm.

R.L.M.: Abbreviation for a dome type of lighting reflector.

r.p.m.: Abbreviation for revolutions per minute.

R.S.A.: Railway Signal Association.

racing of motor: A rapid change or excessive speed of a motor.

raceways: Metal molding or conduit that has a thinner wall than standard rigid conduit used in exposed wiring.

rocks and hooks: Supports for lead covered cables placed in underground manholes.

radial: In a straight line from the center outward.

radian: The angle at the center of a circle where the arc of circumstance is equal to the radius of the circle. It is 57.3 degrees.

radiation: The process of giving off or sending out light or heat waves.

radio: Referring to methods, materials, and equipment for communicating from one place to another without the use of wires between them.

radioactive: Giving off positive and negative charged particles.

rail bond: A short piece of wire or cable connecting the end of one rail to the next.

rating: The capacity or limit of load of an electrical machine expressed in horsepower, watts, volts, amperes, etc.

ratio: The relation of one number or value to another.

ratio arms: The two arms of a Wheatstone bridge whose resistances are known and form the ratio of the bridge.

ratio of a transformer: The relation of the number of turns in the primary winding to the secondary winding.

reactance: The influence or action of one turn of a coil or conductor upon another conductor which chokes or holds back an alternating current but allows a steady direct current to flow without any opposition.

reactance coil: A choke coil. It is used to hold back lightning and other high frequency currents in a circuit.

reactive current: That part of the current that does not do any useful work because it lags behind the voltage.

reactive load: A load, such as magnets, coils, or induction motors, where there is reactance which causes the current to lag behind the voltage.

reactor: Choke coils or condensers used in a circuit for protection or for changing the power factor.

reamer: A cone shaped tool used with a hand brace to remove the burr on the inner edge of conduit.

receiver: The part of the telephone that changes the talking current into sound that can be heard by the ear.

receiving sets: Devices used to receive radio messages and especially radio broadcast programs.

receptacle: A device placed in an outlet box to which the wires in the conduit are fastened, enabling quick electrical connection to be made by pushing an attachment plug into it.

receptacle plug: A device that enables quick electrical connection to be made between an appliance and a receptacle.

reciprocal: One divided by the number whose reciprocal is being obtained. The reciprocal of 2 is ½; of 3 is ⅓, etc.

recorder: A device that makes a record on paper of changing conditions in a circuit, apparatus, or equipment.

rectifier: A device that changes alternating current into continuous or direct current.

rectigon: Trade name for a battery charging rectifier.

red lead: Minimum, or peroxide of lead, used in making pasted battery plates.

re-entrant: Armature windings which return to a starting point, thus forming a closed circuit.

reflector: A device used to direct light to the proper place.

regenerative braking: Using electric motors on a car or locomotive as generators to slow down the train.

regulation: A change in one condition which causes a change in another condition or factor.

regulator: A device for controlling the current or voltage, or both, from a generator or through a circuit. Devices for controlling other machines.

relay: A device by which contacts in one circuit are operated by a change in conditions in the same or another circuit.

reluctance: The resistance to flow of magnetism through materials.

reluctivity: The reciprocal of permeability. The resistance to being magnetized.

remagnetizer: A large direct-current electromagnet used to magnetize the permanent magnets that have lost their magnetism.

remote control: Operating switches, motors, and devices located some distance from the control point by electrical circuits, relays, electromagnets, etc.

renewable fuse: An inclosed fuse so constructed that the fusing material can be replaced easily.

repeater: A device that reproduces the signals from one circuit to another.

repeating coil: An induction coil or transform r used in telephone work that has the same number of turns on each winding.

repulsion: The pushing of two magnets away from each other.

repulsion induction motor: An alternating current which operat s as a repulsion motor during the starting period and as an induction motor at normal speed.

residual magnetism: The magnetism retained by the iron core of an electromagnet. Often the flow of current is stopped.

resistance: That property of a substance which causes it to oppose the flow of electricity through it.

resistance bridge: A Wheatstone bridge.

resistance furnace: A furnace where heat is obtained by electric current flowing through resistance coils.

resistor: Several resistances used for the operation control or protection of a circuit.

resonance: A condition in a circuit when the choke coil reactance is exactly balanced or equalized by a condenser.

resultant: The sum of two forces acting on a body.

retarding coil: A choke coil.

retentivity: Holding or retaining magnetism.

retriver: Device that pulls down the trolley pole of a car when the trolley wheel leaves the wire.

return circuit: The path the current takes in going from the apparatus back to the generator.

return feeders: Copper cables connected at different points of the rail to carry the current back to the generators.

reverse: Going in the opposite direction.

reverse current relay: A relay that operates when the current flows in the opposite direction to what it should.

reverse phase: A change in the phase of the current due to changing the generator or circuit wiring.

reverse power: Sending electric energy in the opposite direction in a circuit to the usual direction.

reversing switches: Switches used to change the direction of rotation of a motor.

rheostat: A resistance having means for adjusting its value.

ribbon conductor: A conductor made from a thin flat piece of metal.

right-hand rule: A rule used to determine the direction of flow of current in a dynamo.

ring armature: An armature with a core in the shape of a ring.

ring oiling: A system of oiling where a ring on the shaft carries oil to the top of the bearing.

ring system: Where two transmission lines from a station are joined together at a substation, thus forming a loop or ring.

risers: Wires or cables that are run vertically from one floor to another and supply electric current on these floors.

rocker arms: The arms to which the brush holders of a motor are fastened or supported.

rodding: Pushing short rods which are joined together through a conduit in order to pull a cable into it.

Roentgen rays: Similar to X-rays.

rosettes: A device to permit a drop cord to be attached to a ceiling outlet or fixture.

rotary converter: A direct-current motor with collector rings connected to the armature windings which changes alternating to direct current or the reverse: a synchronous converter.

rotary switch: A switch where the circuit is opened and closed by turning a knob or handle.

rotor: The part of an electrical machine that turns or rotates.

rotor slots: Openings punched in the disk of the rotor and in which the winding is placed.

r.p.m.: Abbreviation for revolutions per minute.

r.p.s.: Abbreviation for revolutions per second.

rubber-covered wire: Wires covered with an insulation of rubber.

rubber gloves: Insulated gloves worn by linemen when working on "Live" lines.

rubber tape: An adhesive elastic tape made from a rubber compound.

runner: The revolving part of a water turbine.

running torque: The turning power of a motor when it is running at rated speed.

runoff: The quantity of water flowing in a stream at any time.

s.: Abbreviation for second of time.

S.A.E.: Society of Automotive Engineers.

s.c.: Abbreviation for single contact.

s.c.c.: Abbreviation for single cotton-covered wire.

S.E.D.: Society for Electrical Development.

s.c.e.: Abbreviation for cotton enameled wire.

s.p.: Abbreviation for single pole.

S.S.: Abbreviation for steamship when placed before the name of the vessel.

s.s.c.: Abbreviation for single silk-covered wire.

S.K.F.: The trade name for a ball bearing.

safe carrying capacity: The maximum current a conductor will carry without overheating.

safety catch or fuse: A device that opens the circuit when it becomes too hot; often placed in base of appliances for heating liquids.

safety switch: A knife switch inclosed in a metal box and opened and closed by a handle on the outside.

salammoniac: Common name for ammonium chloride, NH_4Cl, used as electrolyte in primary cells.

salient poles: The ordinary poles formed at the end of a magnet as distinguished from consequent poles.

saturation curve: A curve showing the relation between the voltage produced by a generator and the ampere turns on the field coils.

Scott connection: A transformer connection for changing alternating current from two- to three-phase or the reverse.

seal: A piece of lead or metal used to close meter to prevent tempering.

second: $\frac{1}{60}$ part of a minute.

secondary: The circuit that receives power from another circuit, called the primary.

secondary battery: A storage battery.

secondary circuit: The wiring connected to the secondary terminals of a transformer, induction coil, etc.

secondary currents: Currents produced by induction due to changes in current values in another circuit.

section: An insulated length of line or circuit fed by a separate feeder.

sediment: Loose material that drops off storage battery plates and separators into bottom of cell.

segment: One of the parts into which an object is divided; often used to refer to commutator bars.

selector switch: A switch used in an automatic telephone system to locate an idle line.

selenium: A rare metal, the resistance of which changes when under action of light.

self-cooled transformer: A transformer in which the windings are cooled by contact with air or oil and without additional means for radiation.

self-discharge: The discharge of a cell due to leakage or short circuit inside of it.

self-excited: A generator in which the current in the field coils is produced by the generator itself.

self-induced current: An extra current produced in a circuit by change of the current flowing in that circuit.

self-inductance: The magnetic property of a circuit that tends to oppose a change of the current flowing through that circuit.

separators: Wood or rubber plates placed between the plates of a storage battery.

semaphore: A post or stand supporting a railroad signal.

separately-excited: A generator in which the current for the field coils is obtained from another generator or battery.

series: Connected one after another so the same current will flow through each one.

series arc lamp: An arc lamp in which the same current flows through all the lamps connected to the circuit.

series circuit: A circuit in which the same current flows through all the devices.

series generator: A constant-current generator used for operating a street lighting circuit where all lamps are connected in series.

series motor: A motor where all the current flows through the field coils and armature, because they are connected in series.

series-multiple: Same as series parallel.

series-parallel: An arrangement where several devices are connected into series groups and these groups are connected in parallel with each other.

series transformer: A current transformer. A transformer where the primary is connected in series with the circuit.

series winding: A wave-wound armature. A field coil winding through which the armature current flows.

service connections: The wiring from the distributing mains to a building.

service switch: The main switch which connects all the lamps or motors in a building to the service wires.

service entrance: The place where the service wires are run into a building.

service wires: The wires that connect the wiring in a building to the outside supply wires.

sheath: The outside covering which protects a wire or cable from injury.

shell transformer: A transformer with the iron core built around the coils.

shellac: A gum dissolved in alcohol, which forms a good insulating liquid.

sherardising: Coating iron or steel with zinc to prevent rusting.

short: A contraction for short circuit.

short circuit: An accidental connection of low resistance joining two sides of a circuit, through which nearly all the current will flow.

short shunt: Connecting the shunt fields directly to the armature of a compound generator or motor instead of having them in parallel with armature and series fields.

short time rating: A device that can only operate for a short time without being allowed to cool.

shunt: A parallel circuit. A bypass circuit.

shunt coil: A coil connected in parallel with other devices and through which part of the current flows.

shunt field: A field winding connected in parallel with the armature.

shunt ratio: The ratio of current flowing through the shunt circuit to the total current.

shunt winding: A winding connected in parallel with the main winding.

shuttle armature: An H-type armature.

silicon bronze: A bronze or brass containing silicon and sodium which give it strength and toughness.

silicon steel: An alloy steel having low hysteresis and eddy current loss, used in transformer cores.

silk-covered wire: Small copper wires insulated by a covering of silk threads.

simplex circuit: A telegraph which sends in only one direction at a time.

simplex winding: A type of armature winding with two parallel paths from one brush to another.

sin: Abbreviation for sine of an angle; as sin 30°.

sine of an angle: In a right angle triangle it is the length of the side opposite the angle divided by the hypotenuse.

sine wave: The most perfect wave form. An alternating-current wave form.

single contact lamp: An automobile lamp which has one contact in end at base which makes contact with the socket; the side of the base and socket completes the circuit.

single phase: A generator or circuit in which only one alternating-current voltage is produced.

single-phase circuit: A 2- or 3-wire circuit carrying a single-phase current.

single-phase motor: An alternating-current motor designed to operate from a single-phase circuit.

single-pole switch: A switch that opens and closes only one side of a circuit.

single-stroke bell: A bell that strikes only once when the circuit is opened or closed.

single-throw switch: A knife switch that can be closed to one set of contacts only instead of two, as with a double-throw switch.

single-wire circuit: A circuit using one wire for one side and ground for the other side or return conductor.

single re-entrant: An armature winding in which the circuit is traced through every conductor before it closes upon itself.

sinusoid: A sine curve.

six phase: A circuit or machine where the voltage waves are 1/6 of a cycle behind each other.

skin effect: The action of alternating current that causes more of a current to flow near the outside than in the center of a wire.

slate: A rock that is cut into slabs and used for switchboards. It is a fair insulator.

sleet cutter: A device placed on the trolley wheel to cut or scrape sleet from the trolley wire of a railway system.

sleeve joint: Joining the ends of two wires or cables together by forcing the ends into a hollow sleeve and soldering them.

sleeving: A small woven cotton tube slipped over the ends of armature leads to give additional insulation.

slide wire bridge: A Wheatstone bridge in which the balance is obtained by moving a contact over a wire.

slip: The difference in speed between the speed of a rotating magnetic field and the rotor of an induction motor.

slip ring: A ring placed on a rotor, which conducts the current from the rotor to the external circuit. Collector ring.

slot: The groove in the armature core where the armature coils are placed.

slot insulation: Material placed in armature slot to insulate the coils for the core.

slow-burning insulation: An insulation that chars or burns without a flame or blaze.

smooth core: An armature where the conductors are bound on the surface instead of being placed in slots or grooves.

snap switch: A rotary switch where the contacts are operated quickly by a knob winding up a spring.

sneak current: A weak current that enters a telephone circuit by accident. It will not blow a fuse, but it will do damage if allowed to continue.

soaking charge: A low rate charge given to a storage battery for a long time to remove excess sulphate from the plates.

soapstone: A soft oily stone sometimes used for insulating barriers. The powder is used when pulling wires into conduit.

socket: A receptacle or device into which a lamp bulb is placed.

sodium chloride: Common ordinary salt.

soft-drawn wire: Wire that has been annealed and made soft; often being drawn to size.

soldering flux: A compound that dissolves the oxide from the surfaces being soldered.

soldering paste: A soldering flux prepared in the form of a paste.

solenoid: A coil of insulating wire wound in the form of a spring or on a spool.

solenoid core: The soft iron plunger or body placed inside a solenoid.

solid wire: A conductor of one piece instead of being composed of a number of smaller wires.

sounder: A telegraph relay that delivers a sound at the receiving end which the operator can understand.

south pole: The end of a magnet at which the lines of force enter.

space factor: The actual cross-sectional area of copper in a winding divided by the total space occupied by the insulation and winding.

spaghetti insulation: A closely woven cotton tube impregnated with an elastic varnish that is slipped over ends of bare wires to insulate them.

spark coil: An induction coil used to produce a high voltage which causes a spark to jump a gap.

spark gap: A device which allows a high voltage current to jump a gap.

spark plug: A threaded metal shell having a center insulated conductor, which is screwed into the cylinder of an automobile engine.

spark voltage: The lowest voltage that will force a spark between two conductors insulated from each other.

sparking at brushes: Small arcs or flashes occurring between the commutator and brush, due to poor contact or incorrect brush position.

sparkless commutation: Operation of a direct-current generator or motor without any sparking at the brushes.

specific gravity: The weight of any volume of liquid or solid divided by the weight of an equal volume of water; or of any gas divided by an equal volume of air.

specific resistance: The resistance of a cube of any material which is one centimeter long on each edge.

speed counter: An instrument that records the number of revolutions made by a shaft.

speed regulation: The per cent of full load speed that the speed of a motor changes, when the load is suddenly removed.

sphere gap: A spark gap formed between two spheres fastened to conductors.

spherical candle-power: The average candle-power from a light measured in all directions.

spider: A cast-iron frame with radially projecting arms on which the rotating part of an electrical machine is built.

splice: The joining of the ends of two wires or cables together.

splice box: An iron box in which cable connections and splices are made.

split knobs: Porcelain knobs made into two pieces to receive a wire or cable and hold together by a screw.

split phase: Obtaining currents of different phases from a single-phase circuit by use of reactances of different value in parallel circuits.

split-phase motor: A three-phase motor that is operated by split-phase current obtained from a single-phase circuit.

split-pole converter: A synchronous converter with divided or additional field poles for regulating the voltage.

sponge lead: Porous lead used in the active material of the negative plate of an acid storage battery.

spot welding: Uniting two metals together by electric welding them at several spots.

square mil: The actual area of a wire or conductor expressed in mils. The $\frac{1}{1,000,000}$ part of a square inch.

squirrel cage: The arrangement of copper rods in cylindrical form and fastened to copper rings at each end of the rotor core of an induction motor.

squirted filament: The old method of forcing a soft material for a lamp filament through small holes

staggering of brushes: Arranging the brushes on a commutator so they will not all bear or rub on the same place

stalling torque: The twisting or turning power of a motor, just before the armature stops turning, due to heavy load being applied.

standard candle: A standard of lighting power.

standard cell: A primary cell that gives the legal standard of voltage.

standard ohm: The unit of resistance.

standard resistance: An accurate resistance that is used for comparison with unknown resistances.

stand-by battery: A storage battery connected to the distribution system to carry the load should the generators fail.

static machines: Generators that produce static electricity.

star connection: Connecting one end of each phase of a three-phase circuit or machine together, thus forming a common point called the neutral. A Y-connection.

starter: A device that enables a safe current to be supplied to a motor when starting.

starting battery: A storage battery designed to deliver current to a motor used for starting an automobile engine.

starting box: A rheostat used for a short time when starting a motor.

starting current: The current taken by a motor when starting.

starting motor: A motor used for cranking an automobile engine.

starting rheostat: A starting box.

starting torque: The turning power produced by a motor when the rotor begins to turn on that power required to start a machine at rest.

static charge: A quantity of electricity existing on the plates of a condenser.

static electricity: Electricity at rest as distinguished from electric current, which is electricity in motion.

static generator: A machine producing static electricity.

static transformer: An ordinary transformer in which all parts are stationary as distinguished from the earlier constant-current transformer with a moving coil.

stator: The stationary part of an induction motor on which the field windings are placed.

steady current: A direct current whose voltage does not change or vary.

step-down: Reducing from a higher to a lower value.

step-up: Increasing, or changing from a low to a higher value.

stop charge device: A device that disconnects a storage battery from the charging circuit when it is completely charged.

storage battery: A number of storage cells connected together to give the desired current and voltage and placed in one case.

storage cell: Two metal plates or sets of plates immersed in an electrolyte in which electric current can be passed into the cell and changed again into chemical energy and then afterwards changed again into electrical energy.

strain insulator: An insulator placed in a guy wire to insulate it from the current-carrying wire.

stranded wires: Wires or cables composed of a number of smaller wires twisted or braided together.

stray current: Current induced in a conductor or core and which flows in these parts. The return current of an electric railway system that flows through adjacent pipes and wires instead of the regular return circuit.

stray field: Magnetic lines of force that do not pass through the regular path and therefore do not do any useful work.

stray flux: The lines of force of a stray magnetic field.

stray power: The power losses of an electrical machine due to heating effects, as friction, hysteresis, and eddy currents.

strength of current: The number of amperes flowing through the circuit.

strength of magnetism: The number of magnetic lines of force per unit of area.

strip fuse: A fuse made from a flat piece of metal.

Stubs' wire gauge: An iron wire gauge, often called Birmingham wire gauge.

sub-station: The building or place where one form of electrical energy is changed into another, as alternating current into direct current, high voltage to low, or the reverse.

sulphating: The forming of a hard white substance on the plates of a storage battery.

sulphuric acid: The kind of acid that is diluted and put in a lead storage battery.

superposed circuit: An additional circuit obtained from a circuit used for another purpose without interfering with the first circuit.

surface leakage: The leaking of current over the surface of an insulator from one metal terminal to another.

surges: An oscillating high voltage and current waves that travel over a transmission line after a disturbance.

surging discharge: A high voltage oscillating discharge.

susceptance: One of the components in an alternating circuit; the power component is called conductance and the wattless component is called susceptance.

susceptibility: The ratio of the amount of magnetism produced in a body to the magnetzing force.

suspension insulator: An insulator hung from a support and with the conductor fastened to the bottom of the insulator.

swinging cross: The blowing together of the wires of a transmission line, causing a short-circuit.

switch: A device for closing, opening, or changing the connections of a circuit.

switch blade: The movable part of a switch.

switchboard: The panel or supports upon which are placed the switches, rheostats, meters, etc., for the control of electrical machines and systems.

switchboard instruments: Meters mounted on a switchboard.

switch house or room: The part of the building in a power plant where the high voltage switches are located.

switch plate: A small plate placed on the plastered wall to cover a push button or tumbler switch.

switch tongue: The movable part of an electric railway track switch.

symbol: A letter, abbreviation, or sign that stands for a certain unit or thing.

synchronism: Alternating-current voltage waves that have the same frequency and reach their maximum value at the same instant.

synchronise: To bring to the same frequency and in phase.

synchronizer: A device for indicating when two machines are in synchronism.

synchronoscope: An instrument which shows when two machines are in synchronism and which machine is leading the other in phase.

synchronous condenser: A synchronous motor operated without load and strong field current in order to improve the power factor.

synchronous converter: A direct-current motor fitted with collector rings and used to change alternating to direct current.

synchronous motor: An alternating-current motor whose speed is in proportion to the frequency of the supply current and the number of poles in the machine.

synchronous phase advancer: A synchronous motor operated as a condenser to improve the power factor.

T: Abbreviation for temperature.

t: Abbreviation for time in seconds.

Ta: Chemical symbol for tantalum.

T-connector: A connector joining a wire to two branch circuits.

T-splice: A connection joining the end of one wire to the middle of another one.

tachometer: An instrument that shows the number of revolutions per minute made by a shaft.

talc: Powdered soapstone.

tan: An abbreviation for tangent of an angle.

tangent: A straight line that just touches the circumference of a circle.

tangent galvanometer: A galvanometer operated by current passing through a coil overcoming the earth's magnetism.

tap: A wire connected some distance from the end of the main wire or conductor.

tape: A narrow strip of treated cloth.

tapering charge: Charging a storage battery at constant voltage. The rate of current flow will decrease as the battery becomes charged.

taping: Wrapping layers of tape around a wire, coil, or conductor.

teaser winding: An extra winding on the poles of a series wound dynamo.

teeth of armature: The projections between the slots in an armature.

telegraph: A system of sending messages by dot and dash signals.

telegraph relay: A relay used in a telegraph circuit.

telegraph code: The dot and dash signals used for letters or words.

telephone: A device that transmits speech and sound from one place to another by electric currents.

telephone cable: A number of small insulated copper wires bound together and covered with paper, cotton, braid, or lead covering.

telephone condenser: A condenser used in a telephone circuit, made by rolling strips of tin foil between sheets of paraffin paper.

telephone cord: Several very flexible wires covered with a cotton braid. Used to connect one part to another.

telephone exchange: The place where all telephone lines end and connections are made from one line to another.

telephone jack: A receptacle into which a plug is placed when connecting one telephone line to another.

telephone receiver: A device that changes electric current in the telephone circuit into sound.

telephone repeating coil: A transformer used to reproduce the signals from one circuit to another.

telephone set: All the parts, such as transmitter, ringer, receiver, etc., installed for the subscriber's use on his premises.

temperature: Condition in regard to heat and cold.

temperature coefficient: The rate of change in resistance per degree change in temperature.

temperature correction: The amount that must be added to a reading taken at one temperature in order to make it comparable with the same reading taken at a standard temperature.

temperature rise: The difference in temperature between a certain part of a machine and the surrounding air.

tension: The degree of stretching; also sometimes used to refer to voltage, difference of potential, or dielectric stress.

terminal: A connecting device placed at the end of a wire, appliance, machine, etc., to enable a connection to be made to it.

terminal lug: A lug soldered to the end of a cable so it can be bolted to another terminal.

terminal pressure: The voltage at the generator or source of supply.

Tesla coil: An induction coil on a transformer without an iron core, used to produce high frequency currents.

test clip: A spring clip fastened to the end of a wire used to make connections quickly when testing circuits or devices.

test lamp: An incandescent lamp bulb and socket connected in a circuit temporarily when making tests.

test point: The metallic end of an insulated conductor used in making tests.

test set: Electrical instruments and devices used for testing, mounted for convenient use.

testing transformer: A transformer designed to deliver a number of different voltages, and used in testing for defects.

theater dimmers: Variable rheostats connected in series with a lighting circuit to control the voltage to the lamps and amount of light produced by them.

thermal: Pertaining to heat.

thermocouple: Two different metals welded together and used for the purpose of producing thermo-electricity.

thermo-electricity: Electricity produced by the heating of metals.

thermo-galvanometer: A galvanometer operated by the heating effect of a current acting on a thermocouple.

thermometers: Instruments for indicating relative temperatures.

thermostat: A device that opens and closes a circuit when the temperature changes.

third-brush generator: A small generator placed on an automobile to charge a storage battery.

third-brush regulation: A generator whose voltage is regulated by armature reaction and the shunt field current obtained from a third brush bearing on the commutator.

third rail: An insulated rail, placed along side of the rails on an electric railway, which supplies the power to the cars.

three-phase: A generator or circuit delivering three voltages that are $\frac{1}{3}$ of a cycle apart in reaching their maximum value.

three-phase circuit: A circuit delivering three-phase current.

three-phase motor: An alternating-current motor that is operated from three-phase circuit.

three-pole: A switch that opens and closes three conductors or circuits at one time.

three-way switches: A switch with three terminals by which a circuit can be completed through any one of two paths.

three-wire circuit: A circuit using a neutral wire in which the voltage between outside wires is twice that between neutral and each side.

three-wire generator: A direct-current generator with a balancer coil connected to the armature windings and the middle point of the balancer coil connected to the neutral.

tie wire: A short length of wire used to fasten the overhead wires to a pin insulator.

time switch: A switch controlled by a clock that opens and closes a circuit at the desired time.

timer: A device that opens the primary circuit of an induction coil at the right time to produce a spark to fire the charge in an internal combustion engine.

tinfoil: Sheets of tin rolled out thinner than paper.

tinned wire: Wire covered with a coating of tin or solder.

torque: The twisting or turning effort.

torsion dynamometer: An instrument that measures the torque of a machine by twisting a calibrated spring.

track circuit: The circuit through the rails and bonds.

track return: The return circuit formed by the rails and bonds of a track.

train lighting battery: A storage battery used to furnish electricity for lighting railroad cars.

transformer: A device used to change alternating current from one voltage to another. It consists of two electrical circuits joined together by a magnetic circuit formed in an iron core.

transformer coil: A part or one of the windings of a transformer.

transformer efficiency: The power delivered by a transformer divided by the power input to it.

transformer loss. The difference between the power input and output.

transformer oil: Oil used in a transformer to insulate the windings and carry away the heat.

transformer ratio: The ratio of the primary to the secondary voltages.

transformer substation: A substation where the alternating-current voltage is stepped up or down by use of transformers.

transite: A kind of asbestos lumber used for insulating barriers in dry places.

transmission line: High voltage conductors used to carry electrical power from one place to another.

transmitter: The telephone device that receives the speech and changes it into electric current.

transposition: Changing the relation of telephone and electric light wires to each other in order to equalize the inductance and prevent cross talk.

trickle charge: A low rate of charge given a storage battery.

triphase: Same as three-phase.

triple-pole switch: Same as a three-pole switch

trolley wire: A wire supported over the tracks of an electric railway which carries the power for operating the cars.

true resistance: Actual resistance measured in ohms as compared to counter-electromotive force.

trunk: The wires or circuits between switchboards or telephone exchanges.

tube insulator: Insulating material made in the form of a tube and used to carry conductors through walls and partitions.

tumbler switch: A switch similar to a flush push button, but operated by pushing up or down on a short lever.

tungar rectifier: A rectifier using a tungar bulb made or licensed by the General Electric Company.

tungsten: A very hard metal with a high melting point that resists the effects of arcing.

tungsten filament: A filament made from tungsten and used in a lamp bulb.

tungsten steel: An alloy of steel and tungsten which produces a hard tempered steel which retains this property when heated a dull red.

twin cable: Two insulated wires running side by side without being twisted and covered with a braid.

twisted pair: Two rubber-covered telephone wires twisted together and used to connect subscriber's set to overhead wires or cable.

two-phase circuit: A circuit in which there are two voltages differing by one quarter of a cycle.

two-phase motor: A motor made to be operated from a two-phase circuit.

two-phase generator: A generator producing two-phase current.

two-pole: A switch that opens or closes both sides of a circuit or two circuits at one time.

two-wire circuit: A circuit using two wires.

U

ultra violet rays: Light rays that are beyond the violet color and not visible.

unbalance load: A distribution system where there is a greater load on one phase or side than on the other.

undamped waves: Radio waves whose maximum rise and frequency is constant.

under-charged battery: A storage battery that has not been sufficiently charged.

under-compounded: A compound-wound generator in which the voltage drops as the load increases.

under-cut mica: Cutting the mica between commutator segments below the surface so it will clear the brush.

underground cable: A cable insulated to withstand water and electrolysis and placed in underground conduit.

underload circuit breaker: A conduit breaker that opens when the load drops below a certain value.

underload relay: A relay that operates another circuit when the load drops below a certain value.

Underwriters' Code: The National Electric Code.

unidirectional current: Current that flows in one direction.

uniphase: A single-phase alternating current

unipolar: Having one pole.

unit price: Cost of one piece, foot, pound, or whatever number is taken as a unit for that particular material.

unloader: A device that removes the load from a machine, such as a compressor, when a motor is starting it.

V

V: Abbreviation for volts or potential difference.

V.T.: Abbreviation for vacuum tube or electron tube.

vacuum cleaner: A machine that sucks dust and dirt out of rugs, drapes, upholstery, etc.

vacuum impregnated: Filling the spaces between electric parts with an insulating compound while they are placed in a vacuum.

vacuum tube: Any kind of a bulb or tube from which the air has been removed.

vapor: A gas from a substance that is ordinarily a liquid or solid.

vapor rectifier: A mercury arc rectifier.

variable condenser: A condenser whose capacity can be varied.

variable resistance: A resistance that can be changed or adjusted to different values.

variable-speed generator: A generator operated at different speeds with a method of regulation which causes it to deliver a constant voltage.

variable-speed motor: A motor whose speed depends upon the load.

Varley loop: A method of locating a cross, short-circuit, or ground on telephone or telegraph lines.

varnished cambric or cloth: Cotton cloth treated with an insulating varnish.

vector: A line whose length and direction represents a certain physical quantity.

vector diagram: A diagram that shows relations by use of vectors.

verdigris: A substance called copper sulphate that forms on copper by the action of sulphuric acid.

vibrating rectifier: A device that changes alternating current into direct current by means of a vibrating contact that closes the circuit for one-half of the cycle and opens it when the flow of alternating current is in the opposite direction.

vibrator coil: An induction coil used as an ignition coil.

volt: A unit of electrical pressure or electromotive force.

voltage coil: A coil connected across the line so that the current flowing through it changes as the voltage changes.

voltage drop: The difference in pressure between two points in a circuit caused by the resistance opposing the flow of current.

voltage loss: The voltage drop.

voltage regulator: A device for keeping a constant voltage at a certain point.

voltaic battery: A number of primary cells connected in series or parallel.

voltammeter: A voltmeter and ammeter combined in one case and using the same movement, but having separate terminals.

volt-ampere: The unit of apparent power; it is the product of the pressure times the current.

voltmeter: An instrument that shows the pressure or voltage of a circuit

vulcabeston: An asbestos and rubber composition used to make moulded parts.

vulcanite: A kind of hard rubber.

vulcanized fiber: An insulating material made of paper and cellulose under heavy pressure.

W

W: Abbreviation for watt.

W.A.E.I.: Western Association of Electrical Inspectors.

wall box: A metal box for switches, fuses, etc., placed in the wall.

wall insulator: An insulating tube used to protect a conductor passing through a wall.

wall socket: An electric outlet placed in the wall so that conductors can be connected to it by means of a plug.

water-cooled transformer: A large transformer having coiled pipes inside it through which water passes.

water rheostat: A rheostat that has its terminals placed in water through which the current flows.

watt: The unit of electric power.

watt-hour: The use of a watt of power for an hour.

watt-hour meter: An instrument that records the power used in watt-hours.

watt meter: An instrument used to indicate the power being used in a circuit.

watt minute: A power of one watt being used for one minute. $\frac{1}{60}$ of a watt-hour.

wattless: Not having any power or doing any useful work.

wave meter: An instrument used to determine the wave length or frequency of a radio broadcasting station.

wave winding: An armature winding with the end of the coils connected to commutator bars that are nearly opposite each other in a 4-pole machine.

weatherproof: Constructed so it will resist the action of rain, sun, etc.

welding transformer: A transformer built to deliver a large current used to heat metals to a welding temperature.

welding flux: A material, usually borax, used to remove scale from the joints being welded.

Western Union splice: A method of uniting two wires together by wrapping each one about the other.

Western cell: A primary cell that has a constant voltage and used as a standard source of electrical pressure.

wet storage: A method of keeping a storage battery when it is not being used without removing the acid or plates.

Wheatstone bridge: An electrical balance used to measure resistance by comparing a known resistance with an unknown.

windage: The resistance of air against the rotating part of a machine.

wiping contact: A contact that rubs between two other contacts.

wire: A slender rod of drawn metal.

wire gauge: A method of expressing the diameter of different wires.

wired radio: Transmitting radio messages along telephone, electric light, and power lines instead of directly through the air.

wiring connector: A device for joining wire to another.

wiring symbols: Small signs placed on a wiring diagram to indicate different devices and connections.

wood separator: A thin sheet of wood placed between the plates of a storage.

wrought iron: A kind of iron that can be easily magnetized.

X

x: A symbol used to represent an unknown quantity.

x: A symbol for reactance, expressed in ohms.

X-ray: A kind of ray that passes through most materials as if they were transparent.

Y: A symbol for admittance; the unit of which is mho.

Y-connection: A star connection; the joining together of one end of each phase of a 3-phase machine.

yoke: The iron frame of a generator or motor to which the magnetic pole pieces are fastened.

Z: Symbol for impedance.

zero potential: Not having any voltage or pressure.

zinc battery: A primary cell in which the electric current is produced by zinc plates immersed in an electrolyte.

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